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EROSION AND SOIL CONSERVATION

by

G. V. JACKS and R. O. WHYTE

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PREFACE

In compiling this account of contemporary soil erosion we have had the active co-operation of our Official Correspondents and other workers throughout the world. From these sources we have received valuable and often otherwise inaccessible information in the form of specially prepared memoranda, reprints, copies of legislation, press reports and other occasional literature. In some cases, the memoranda summarized the position so adequately that we, as compilers, felt unable to improve upon them, and we have incorporated them verbatim in the text. We take this opportunity of thanking our many collaborators for the invaluable assistance they have given ; without them the merits of this publication would have been fewer, and its deficiencies far more apparent, than they are. We wish also to thank those who, possessing a personal and more intimate knowledge than ourselves of local conditions, have read, criticized and often substantially improved our first drafts.

The paper has aimed at describing the present position with regard to erosion in the most seriously affected countries, the causes that have brought erosion into being, and the measures that are being taken or are contemplated to eliminate the causes and mitigate their effects. Taking into consideration all the circumstances under which the paper was written, we decided that the best arrangement would be geographical, allotting a separate section to each political unit, since national aspects of the erosion problem are likely to dominate control policies for some time to come. We have included every country about which information was obtainable, but for certain countries, notably in South America and Africa, no suitable studies on erosion have been published, or at least have come to our notice, and we have omitted these countries from our discussion regardless of whether or not the known conditions of land utilization are likely to have resulted in erosion. We have also passed over certain western European States where torrent and erosion control are matters of local rather than national concern.

The paper does not set out to give general technical information on appropriate measures of soil conservation, flood and erosion control, etc. Such information is fully given in several excellent text-books on soil erosion which have recently appeared, particularly in the United States, and is now also freely obtainable in many countries in the form of official circulars and bulletins from agricultural, forest and public-works Departments, or of advice and instruction from experts and farmers who are responsible for, or have undertaken, successful conservation schemes. The essential principles of soil conservation are fairly well established, but the technique of their application is constantly changing as the wide significance of erosion as a sociological problem becomes increasingly recognized.

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Erosion and Soil Conservation

Mediterranean Region

The countries bordering the Mediterranean were originally well wooded, but their ecological history during the last 3,000 years has been one of gradual but almost continuous deforestation. At the present time, there is practically no forest left anywhere near the sea in the Mediterranean region proper—i.e. excluding southern France and northern Italy. One result has been that all the erstwhile ports on the southern side of Anatolia are now silted up (2).

The region is characterized by cloudless skies for the greater part of the year and by torrential winter rainfall. There is very little frost below 2,000 feet altitude. On loose weathered rock and alluvial soils the conditions are ideal for erosion, the igneous and limestone formations hold up somewhat better. The indiscriminate deforestation and the complete lack of forestry practice during 3,000 years have washed away much of the original soil, the North African deserts where fertile cornfields existed in Roman times bearing witness to the worst results. Owing to the frequent proximity of steep mountains to the sea and the declivity of the eastern Mediterranean beach, most of the eroded soil has been washed into the sea. Deprived of cultivable soil, the agriculturist has turned to goats which have perpetuated the vegetative destruction initiated by deforestation.

According to Peattie's review of the subject (5) there was serious deforestation in the Apennines in Roman times and even earlier in Greece. The demands of Phoenician commerce aided in the denudation of the mountains of Greece. The early demands of the Etruscans on the forests of the Apennines were followed by those of the Romans, and the climate of the deforested mountains did not favour natural regrowth. Attention was then directed to the Alps, but deforestation in the Pyrenees and Alps does not appear to have become serious until the later Middle Ages. Deforestation in these mountains is stated to have been less a result of commercial exploitation than of the over-population of the valleys, with a consequent increased demand for cleared fields, pastures and fuel. Deforestation in France, particularly in the Pyrenees, has caused almost catastrophic erosion, and national attention has been aroused on the question of reforestation of the denuded slopes.

Excerpts from an address by M. Albert Magnein, Inspector General of Administration of Waters and Forests, Paris, on the control and use of little waters in France are published in *Soil Conservation* (4).

For the entire French Territory between 1861 and 1935 the French Administration of Waters and Forests has reforested approximately 1,190,000 acres at a cost of 317 million francs, of which 57 million francs have been spent in corrective works. Such works of correction of torrents and regulation of pasturage cannot be done without injuring certain

private interests. A number of laws permit the Forestry Administration to overcome any resistance which might occur.

The problem of stabilizing sand-dunes also arises in France, arable land having been covered with sand in the Landes before works of dune fixation were undertaken by the Forestry Service in 1862 and continued ever since. These works extend along 720 miles of the French coast and cover approximately 250,000 acres. The works built since 1864 have cost 13 million francs and the annual maintenance costs are in the neighbourhood of 200,000 francs. The stabilization and afforestation of sand dunes has been successfully carried out on a large scale by the Italians in Tripolitania since 1924 (1).

In the second chapter of his book on "Boschi e pascoli" (Woods and pastures), E. Ferrari states (3):

"The change that the climate in Persia underwent after the destruction of its numerous and majestic parks is well known; its territory was transformed into movable banks of white sand, the climate became arid and suffocating, springs of water at first decreased and finally disappeared altogether. Egypt, with the devastation of its forests, saw a decrease in rains, in soil fertility, and in uniformity of its climate. Palestine, at one time covered with valuable forests and fertile pastures, possessed also a cool and moderate climate; to-day its mountains are sadly denuded; the rivers almost dry and crop production reduced to a minimum."

In the following sections of this Bulletin, an attempt will be made to describe the conditions found in Italy, Cyprus, Turkey and Palestine, as representative areas of the Mediterranean region.

References (Mediterranean Region)

1. ABERYSTWYTH, Imperial Bureau of Pastures and Forage Crops. Correspondence on soil erosion in Italy from E. Pantanelli. Bari, 24 November, 1937. pp. 3.
2. AUSTRALIA, 3rd British Empire For. Conf. Papers 691-701. Forestry in relation to climate and erosion in the Mediterranean region. By A. H. Unwin. 1928.
3. FERRARI, E. Boschi e pascoli. [Woods and pastures.] [Quoted in] Halting Italy's shifting sands. By A. Chiera. See *Soil Conserv.* **1.** 14. 1936.
4. MAGNEIN, M. A. Control and use of little waters in France. [Comprising] Excerpts from an address by the Inspector General of Administration of Waters and Forests, Paris, France, before the Upstream Engineering Conference in Washington, D.C., September 22, 1936. *Soil Conserv.* **2.** 124-5 and 130. 1936.
5. PEATTIE, R. Mountain geography. A critique and field study. 24 × 16. pp. xiv + 257. Cambridge, Mass.: Harvard Univ. Press, 1936.

ITALY.

The technical and legislative measures being adopted against soil erosion in Italy comprise only a section of the national programme of land reclamation (bonifica integrale), which has been carried on vigorously since the beginning of the Fascist regime (4).

Integral land reclamation consists in the co-ordinated execution of all the works required to adapt the land and the water on it to such intensive forms of production as will ensure work and higher social standards to a dense rural population.

The general Fascist conception of society as an integral whole has now conferred an integral character on land reclamation. The aggregate of all the works required in any given sector—whether they cover land settlement, social measures, reconditioning of mountain land, the control of water courses, drainage, irrigation, aqueducts, the breaking-up of new lands, the reconditioning and improvement of the soil, experimental work, road-making, the erection of villages, buildings, power stations, the laying of electric lines etc.—all compose integral land reclamation.

Organization

The Mussolini integral land reclamation act came into force in July 1, 1929. Later in the same year the Ministry of National Economy was replaced by a Ministry of Agriculture and Forests, which directs all services connected with reclamation under a special Under-Secretary of State for Land Reclamation. The administrative services have been placed under the orders of the Under-Secretary and are discharged by a General Directorate consisting of six divisions. As the present conception of land reclamation in Italy deals with territories to be reclaimed rather than categories of work to be executed, each division is qualified to deal with a definite territorial area. For the technical services the Under-Secretariat utilizes the Board of Civil Engineers, and the National Forestry Militia, as well as the newly constituted Agrarian Inspectorships.

Public works for which Government is responsible are rarely carried out by its direct action, but by non-government agencies, such as the land-reclamation consortia, to which Treasury grants are made, or by private persons ; Government action is limited to examination and approval of the plans and projects and inspection of the progress of the work. The more complex projects are examined by joint boards containing engineering, forestry and agricultural experts ; the central board is the Superior Council of Public Works. A special land reclamation committee has also been formed to advise the Under-Secretary on the classification of land reclamation boundaries, and if necessary on the appropriation of the lands to be reclaimed.

In 1937 the Under-Secretariat underwent various modifications, as the two public corporations, the National Association of Land Reclamation Consortia and the National Secretariat for Mountain Lands, formerly presided over by the Under-Secretary for Land Reclamation himself and utilized in reclamation work, were suppressed. The reconditioning of mountain land, with which this account is chiefly concerned, is carried on exclusively by the Forest Service (1).

Since erosion takes place in Italy only on clayey slopes and pliocene clays, a very limited amount of control work is necessary for a few valleys

in the Alps, and none on the igneous formations of the Thyrrenian coast, the massive limestones of eastern and southern Italy and Sicily, the archaic chains of southern Calabria, northern Sicily and Sardinia. The problem becomes prominent on the northern slopes of the Apennines, in central Tuscany (Siena and Volterra), in a part of the southern Apennines in Lucania and Calabria and on the hill land in the interior of Sicily and Sardinia. The planting of windbreaks is carried out in Sardinia and Maremma to reduce the blowing of light soils (1).

The problem of the proper utilization of the clays of the Apennine foothills is a fundamental one for Italy (11). These formations cover about 65,000 sq. km. or one-fifth of the country; the Pliocene clayey soils extend over 18,000 sq. km., and erosion has caused sterility and depopulation over great stretches of territory. The problem is typically Italian, the clayey formations being characteristic of the peninsula. They also occupy a considerable area in Sicily.

Special reference should be made to "La bonifica nelle colline argillose plioceniche" for a detailed study of the utilization and control of erosion on these clayey soils, to the works of Passerini on the factors and mechanism of erosion of clay (5, 6, 7, 8), and to papers on hill improvement, such as that by Sabbatini (10).

For technical reasons it is not possible to solve the erosion problem merely by reforestation; even if this were technically possible, social reasons make it necessary to find an agricultural remedy. It is impossible to consider, in a country with the configuration and population density of Italy, the subtraction of so great a part of the hill country from an agrarian production suitable for feeding a stable rural population.

A very early and most detailed study of the Siena clays was made by an Academy in Siena in 1771, but little of practical value was obtained. In 1818 and the subsequent years from 1828 to 1830 Cosimo Ridolfi described his classic work on the levelling and proper utilization of clayey slopes, the aim being to protect them from erosion and at the same time enable them to support a certain number of settlers. This work caused a considerable stimulus in the interest in the problem. In 1840 there followed a memorandum from the Royal University of Siena on the hills of the Volterra region; this stated that the state of lassitude and squalor characteristic of most of the clay lands of this and other parts of Tuscany was caused by neglect of proper control of rain water owing to lack of population, a state of affairs caused by continual wars and disease. It was considered that, with the introduction of proper erosion control methods, it would be economic and profitable to introduce artificial meadows into the rotation, two parts of the whole farm being sown with cereals, and one-seventh kept for grazing small stock.

These early writings may be regarded as having produced the slow but continuous work of hydraulic regulation, terracing, etc., and the subsequent utilization of the Siena, Volterra and other clays with herbaceous crops, which then became one of the traditional types of work on all

Tuscan estates. The movement continued through the nineteenth and into the twentieth century, until in 1907 it is noted that, in the province of Ravenna, an attempt was begun at remedying the disintegration of the clayey zones around Faenza and Brisighella, which resulted in the formation in 1911 of the Consortium for the hydraulic and forestal regulation of the mountainous basins of Brisighella (4, p. 154, and 9). The work done by this Consortium was an incentive for the formation of similar organizations in the Apennines, Emilia and other parts of Italy.

The progress was uncertain and slow, due partly to differences of opinion with the owners of the land, and more especially to the Great War, but the movement received a great impetus in the post-War period, becoming a major part of the Fascist land policy.

The systematization of the clayey hills, aiming at protecting the stability of the land, hydraulic regulation, preservation and increase of rural life, is one of the aspects of "Bonifica integrale". In fact the comprehensive areas already classified for reclamation include extensive clayey hill formations. In order that all the parts available may be properly considered, a complete review of the problem in these foothills of the Apennines has been prepared under the guidance of G. Garavini (2). The scope of the work is restricted at present to the Pliocene clays of the Apennines of Tuscany, Emilia and the Marches.

Where the process of weathering is already well advanced, very expensive operations will be necessary ; the greater part of the cost can be borne only by the State. Preventive action is also necessary where erosion has not yet begun, but adequate means for enforcing these are lacking, except where a Consortium is not only the organ for carrying out public works, but also the organ of control and discipline of the individuals in the observance of rules necessary for the protection of the soil and the rational conduction of the water.

The oak wood may have been the dominating forest formation on the pliocene clays, when they were covered by a mantle of yellow sand or at least by a stratum of clay mixed with sand. Into this upper stratum roots were sunk by the oak wood consisting of *Quercus robur* var. *lanuginosa*, often associated with *Q. cerris*. More or less extensive remains of this formation may be found, nearly always modified in a regressive direction by human action. They cannot, however, be regarded as typical formations of the clayey soil.

In the Volterra district, on the other hand, the remains of forest formations have been observed which may be said to be typical of the pliocene clays. They consist of the dominant association *Fraxinus ornus—Ulmus campestris* forming the upper growth, with the former prevalent to the extent of 70 to 80 per cent, and of an undergrowth of *Prunus spinosa*, *Ligustrum vulgare* and *Crataegus pyracantha*. One cannot judge what growth and mean dimensions would be reached by these species, as they are continually being utilized by the peasants by pollarding and irregular chopping. As a result of lopping and pasturing the greater part of these

forest fringes presents a stage of advanced regression, being reduced to low thickets with predominance of *Prunus spinosa*, *Spartium junceum* and rare stumps of common ash and elm to bear witness to the preceding arboreal composition.

References (Italy)

1. Aberystwyth, Imperial Bureau of Pastures and Forage Crops. Correspondence on soil erosion in Italy from E. Pantanelli. Bari, 24 November, 1937. pp. 3.
2. Garavini, G. See reference 3. p. 157 *et seqq.*
3. Italy, Ministry of Agriculture and Forestry. La bonifica nelle colline argillose plioceniche Preappennino Tosca-Emiliano e Marchigiano. [Reclamation work in the Pliocene argillaceous foothills of the Appennines in Tuscany, Emilia and Marche.] 26 × 18. pp. 364. Rome, 1934. Maps.
4. Longobardi, C. Land-reclamation in Italy. Translated from the Italian by Olivia Rossetti Agresti. 22 × 15. pp. 255. London, 1936. pls.
5. Passerini, G. I calanchi. *Bull. Ist. Agrar. Scandisci.* 1923.
6. ———— La degradazione delle argille plioceniche. [The erosion of the Pliocene clays.] See reference 3. pp. 103-55.
7. ———— L'immunizzazione dell'argilla pliocenica dal logoramento idrometeorico. [The immunization of the Pliocene clay from wearing down by water.] *Atti. Acad. Georgof. Firenze.* **6.** (13). 1935.
8. ———— Influenze della immersione degli strati e dell'orientamento dei Versanti su la degradazione delle argille plioceniche. [Influence of the immersion of the strata and of the direction of the watersheds on the erosion of the Pliocene clays.] *Bull. Soc. Geolog.* **56.** pp. 209-91. 1937.
9. Ringland, A. C. Watershed control in Italy. *Soil Conserv.* **2.** 251, 265 and 266. 1937.
10. Sabbatini, L. Il buon governo delle acque. [Good water regulation.] Roma, 1935. pp. 90. 2nd Ed. [Biblioteca d. Insegnamento Agrario.—Ramo Editoriale degli Agricoltori.]
11. Serpieri. See reference 3, preface, pp. 5-7.

CYPRUS

A special report on erosion in Cyprus prepared by the Assistant Director of Agriculture (Mr. A. Pitcairn), in response to a questionnaire circulated by the Bureaux, forms the basis of this Section (1).

" The climatic and topographic features of the Island provide the requisite natural conditions for rapid erosion ; in the parts of the Island where denudation of surface vegetation has taken place, or where faulty methods of farming, grazing and land management are practised, soil erosion is rapidly going on. Eroded areas have appeared which are difficult to reclaim, the surrounding agricultural land has lost its value, water conservation is affected and the ultimate result is a depressing effect on the economic progress of the community of the area concerned.

" Many of the forests on the mountains and water catchment areas of Cyprus are preserved and there is no doubt that if it was not for this fact very extensive areas of eroded infertile tracts of land would be a feature of the landscape of Cyprus as elsewhere in the Eastern Mediterranean.

Nevertheless, erosion in varying degrees of intensity is constantly going on and it is necessary that all possible measures be taken to bring pressure upon all concerned of the vital importance for the adopting of measures to control every type of abnormal erosion which may have developed."

The characteristic features of the climate are intense heat with practically no rains during the summer months, low average rains in the plains during winter months with snow in the mountains and light winter frosts in the lower regions. The Island is liable to periodic droughts, and to falls of rain of high intensity. Erosion takes place particularly during the early winter rains or following a spell of dry weather during the winter season, when the moisture content of the soil is low. Steady dry easterly winds prevail in spring and autumn, and westerly winds in summer. These winds tend to become drier as they pass over the plains and are of sufficient velocity to blow into the sea the fine soil particles which have been pulverized in summer by the excessive heat, cultivation and trampling of livestock.

Steep slopes and rocky gorges are characteristic features of the mountains and hills. The numerous streams and winter torrents rushing down from both sides of the mountain ranges during the rains remove enormous quantities of soil which is either distributed over the plains as a thin layer of very erodible silt, or carried out to sea. The exposed hills on steep slopes are very susceptible to erosion, especially in soils formed from the loose rocks on certain types of the igneous formation. On average slopes even vineyards do not stand more than forty years.

According to Unwin (2), there are no indications that the climate has changed during the last 3,000 years; the change from fertility to aridity has been due entirely to deforestation. The forests have been more or less preserved for fifty years and, in the closed forests, growth is becoming more rapid from year to year, and a thin humus layer has formed on the soil. The need for preservation in other categories of forests is not fully recognized by the people; the natural vegetation has been seriously disturbed by unrestricted pasturing of sheep and goats; the goat is an important source of livelihood in the hills. The numbers of sheep and goats are now restricted more by deaths through starvation and disease than by flock and pasture management.

Considerable areas have been denuded of certain types of natural vegetation by fuel cutting; with the increasing population in the towns and rural areas the question of fuel supplies becomes more acute from year to year. Fuel grounds are invariably grazing grounds as well. The forest cover of juniper has been destroyed, the surface soil washed away and the underlying limestone rock exposed over the whole of one typical area. Serious erosion on grazing lands is also due to the unrestricted cutting of *Thymus capitata* for village and town fuel supplies and *Sanguisorba spinosa* for fuel and fence making.

The usual measures adopted to decrease the velocity of surface run-off are (a) use of dry stone walls, (b) terracing, (c) strip cultivation, (d)

reclamation of valleys by training and damming streams, (e) tree planting combined with cereal growing in the hills, and (f) irrigation with silt-laden flood waters. The dry stone wall method is the most general and effective method, and is used in a number of different circumstances.

Apart from forestry and its relation to erosion control and the traditional measures of dry stone walling and terracing, the following measures are considered to be necessary to prevent abnormal erosion in Cyprus :

(1) The reduction of sheep and goats in each village area to the numbers the village grazing grounds can normally support.

(2) A change in the system of grazing from unorganized grazing to rotational grazing.

(3) The provision of supplementary feed to grazing animals during the autumn months.

(4) The reduction of the number of goats in the hills.

(5) Prohibition of grazing animals on steep cultivated slopes.

(6) The prevention of intensive " thrumbi " (*Thymus capitata*) cutting on grazing grounds near towns and villages.

(7) Tree planting in the plains and foothills.

(8) The planning of a drainage system in conformity with the erosion control methods.

(9) Strip cropping on the contour where the donum value of crops does not justify the expense of terracing.

(10) Checking the rate of flow of the streams and torrents in the mountains and hills by constructing check dams and by afforestation.

Unwin refers to the excellence of the climate for fruit growing and suggests that horticulture might reconcile the conflicting interests of the conservationist (forester) and the peasant. Lack of initiative on the part of the peasant is a stumbling block, but Unwin considers that an intensive system of horticulture and agriculture combined with properly managed forestry, excluding grazing from the forests, is the most promising line of attack.

Pitcairn concludes his report by stating that data are required on the intensity of the rainfall and the physical and chemical properties of the different soil types in order to determine their relative erodibility.

References (Cyprus)

1. Cyprus, Dept. Agric. Bull. No. 3. Report on soil erosion in Cyprus. By A. Pitcairn. pp. 31. 1937.
2. Unwin, A. H. Forestry in relation to climate and erosion. The Mediterranean region. Paper presented to the British Empire Forestry Conference, Australia and New Zealand, 1928.

TURKEY

On account of its morphological structure, Anatolia affords good opportunities for erosion in all parts, and where climatic conditions are such as to promote erosion, its effects are certain to be serious (1). The reliable historical data available indicate the extent of erosion during the past two thousand years. The whole Cilician plain is an early alluvial deposit which is steadily increasing in size. Tarsus, once visited by Cleopatra's fleet, is now an inland town 15 km. from the sea. Tschikatcheff (4) calculates that the sea at the mouth of the Great Menderez River has receded at the rate of about 600 m. per century within the last 1,900 years. Other important evidence of erosion is provided by the masses of eroded material now filling the characteristic "Ovas" of Anatolia; Salomon-Calvi (3) estimates the depth of alluvial soils of the Ova of Ankara at several hundred metres. It is thus obvious that enormous quantities of soil have been moved in the past, and that this movement will continue, since conditions have not altered.

The climate in the different regions of Anatolia varies widely, consequent upon its topography and its situation between the Mediterranean and the mainland of Asia. Details of the climatic data, together with a draft of a climatic map of Turkey, are given by Christiansen-Weniger (2). From the erosion point of view average precipitation is of little importance, the chief factors being maximal precipitation and the distribution of rainfall in the different seasons. Autumn and winter rains furnish the maximal precipitation on the north coast, while on the west and south coasts, winter rains are characteristic, and there is very little in summer. Important erosion factors are the occasional torrential rainstorms which occur in Turkey, and which have great erosive powers. Further, in parts of the country which suffer extreme drought in summer, dust storms may occur.

As the utilization of the land in the different districts is not in any way uniform, the erosion problems which arise also differ widely. On the Black Sea littoral, for example, deforestation combined with the high rainfall and great differences in altitude due to the proximity of the mountains to the coast are important factors. Agriculturists along this coast have to contend with serious erosion; the crops which are grown, e.g. maize, wheat, barley, and tobacco, do not provide sufficient soil cover, particularly as the land is almost bare, except for weeds, in the wettest months of autumn and winter. The cultivation of hazel nuts is also conducive to erosion in this district. With the intensification and extension of crop growing in this coastal area, terracing will be essential where the cultivation of protective crops is insufficient to control soil washing; as the growing of maize cannot be discontinued, legumes will have to be grown with this crop and used in some particular way. In any case, a thick, protective plant cover is essential in the autumn and winter months.

Quite different conditions are found on the west and south coasts;

here are the great coastal plains and the river valleys, the lateral slopes of which are of particular importance for crop cultivation. In addition to figs and olives in the west, citrus in the south and vineyards for the production of currants, the main crop plants are wheat, barley, tobacco, sesame and cotton, all crops giving little protection against erosion. In these areas the introduction of protective crops is again necessary, with or without terracing, in order to conserve the fertility of the land.

The systematic control of detritus-bearing torrents is an important problem in soil conservation in those parts of central Anatolia where the surface constitution and climate favour their formation. This is of particular importance where there is a danger of irrigated rice fields being buried with river-born detritus. Dust storms also constitute a conservation problem in central Anatolia ; the present form of steppe agriculture does not favour wind erosion, but reorganization on modern lines and an extension of crop cultivation would certainly increase the danger.

The conditions favouring erosion in south-eastern Anatolia are similar to those described for the central part of the country. In eastern Anatolia the great increase in the volume of water subsequent to the rapid thaw of the snows has a marked effect on the erosive powers of the rivers ; in consequence, flooding and deposition of silt occur in the valley plains. The present methods of cultivation reduce the erosion danger considerably ; fields do not cover large areas of slopes, but are continuously interrupted by strips of natural plant cover, while protective crops such as *Onobrychis sativa* and lucerne are grown.

Christiansen-Weniger (1) also considers chemical erosion, the liberation and removal of soluble substances through the action of water, and the formation of saline soils which is a serious danger to crop cultivation in all the arid and semi-arid parts of Turkey.

The problem of erosion in Turkey has many aspects, but in the reconstruction of her agriculture now in progress, the country is still in a position to avoid the errors made in other parts of the world. Those districts most favoured climatically for crop cultivation are also those most subject to erosion, but by the united efforts of the whole agricultural population of a district and the adoption of recognized conservation measures, much can yet be done.

References (Turkey)

1. Christiansen-Weniger, F. The importance of soil erosion for the intensification of field husbandry in Turkey. *Herb. Rev.* **5.** 175-86. 1937.
2. ———————— Grundlagen des türkischen Ackerbaus. [Principles of crop cultivation in Turkey.] Leipzig, 1934.
3. Salomon-Calvi, W. Verbal communication.
4. Tschikatcheff, P. de. Asie mineure. Géologie. [Asia Minor. Geology.] Vol. 3. Paris, 1869.

PALESTINE

The Conservator of Forests for Palestine, Mr. G. N. Sale, states in a memorandum on erosion in Palestine to the Herbage Bureau that no prosperity can possibly be achieved until erosion is controlled in the mixed hill country. Palestine represents a splendid field for the student of erosion, and research scholars could obtain the co-operation of many Government Departments, which are affected by erosion and its consequences.

" The climate is of an extreme Mediterranean type, a long hot summer, with high temperatures, prolonged droughts, periods of extreme atmospheric desiccation with drying winds, alternating with a cool to cold winter, with heavy downpours of rain, mild or cold moist winds from the south-west, and cold dry winds from the north-east and east. By far the greatest part of Palestine is composed of limestone and derivative soils, with extensive basalt masses in the north-east. The limestone varies considerably in hardness, from chalk to marble. Along the coast, and more extensively in the south, are to be found silicious sand dunes affected by the wind, and small masses of sandstone, often formed recently by the deposition of calcareous cement in the sands. A broken range of hills stretching from north to south is interrupted by the large plain of Esdraelon south of Nazareth, and by several other small plains and river valleys, some draining westwards to the Mediterranean, and some eastwards to the Jordan Valley which is below sea level. The watershed varies in height from some 55 m. in the Plain of Esdraelon to 1,200 m. in the extreme north, 700 m. in Samaria, and 1,100 m. north and south of Jerusalem (800 m.).

" The Plains of the Coast and Esdraelon are composed of deep masses of deposited soil, seldom stationary and mature. The hills are almost denuded of soil, and the resultant floods considerably reduce agricultural values in the plains and valleys. One interesting feature is the high percentage of rain water apparently absorbed by bare limestone slopes. Irrigation experts from other countries have expressed surprise that, even where denudation is complete, the run-off is not greater. The absorbed water replenishes a great natural reservoir which underlies much of the coastal plain, and is available for irrigation.

" This fact by no means reduces the importance of erosion or removes the need for control measures. The hill country comprises some 60 per cent of the non-desert area of the country, and could all be habitable and productive. It is in a ruinous state, and many slopes with high rainfall are devoid of permanent vegetation and practically denuded of soil.

" It seems clear that in classical times a high degree of development was to be found in these hills. The inhabitants were often shut out from the plains by warlike foes. Their grazing animals were confined to the neighbourhood of the villages by fear of carnivora and thieves. The horizontal rock strata commonly found encouraged them to discover the method and value of terracing, and in fact terraced cultivation on

slopes was widespread and efficient until prolonged wars and calamities resulted in the decay of this sound practice. Later the spread of nomadic habits involving universal excessive grazing permitted not only the decay of terraces on developed slopes, but the gradual disappearance of the natural vegetation from great areas.

" These changes, far from being checked, have been accelerated by the introduction of Western civilization. Carnivores and cattle thieves, though noxious to individuals, were of value to the community as the only safeguards of the remnants of the scrub vegetation. The extinction of these beneficent pests, and more recently the rise in the market value of hitherto worthless land have resulted in the destruction of many scrub forests, the completion of soil removal, and the consequent cessation of springs over large tracts of the country. Reports are received of floods destroying irrigation and other works standing since Roman or Byzantine times. A main road runs past one ruined water-mill after another, in a valley where now a small stream runs annually for a few weeks only, but where floods periodically destroy public works, flocks, arable fields and human lives. A village named Umm el Fahm (mother of charcoal) brings its charcoal from other places, its oak forests having given place to bare rocks. Another " forest " village cannot find a stick large enough for making ploughs or carts, owing to its practice of uprooting its oaks for charcoal, and grazing its goats on any shoots which may come up. Every goat is now visible in a forest where a generation ago a squadron of cavalry found complete cover.

" The Department of Forests has as its main aim the control of erosion, and as a preliminary step has correlated the activity of a number of Erosion Observers, who report to the Department any interesting cases of erosion which they notice. These reports are mimeographed and circulated to all members, photographs being held for inspection at the Department. The observers include foresters, agriculturists, railway and road engineers, archaeologists, and other scientists. The subject in Palestine, as in other countries, is gradually impinging upon the consciousness of the general public. The very completeness of the destruction encourages inaction, because to the average man it appears merely quixotic to make a start on the long task of reclaiming a wilderness of stony slopes. The comparatively rapid success of small afforestation experiments near main roads, and the contrast of their beauty with the stark ugliness of the neighbouring slopes is, however, having a valuable educational effect. The increase of terracing on slopes, of building walls to reduce aerial erosion, and of planting hardy fruit trees is already apparent, though nothing but periodic disease seems to reduce the excessive number of grazing animals, which patrol everywhere in rural areas, destroying vegetation with complete efficiency.

" Disastrous floods in 1933 and 1934 have attracted attention to the steep Tiberias slope, above the western shore of the Sea of Galilee. It is formed of irregular masses of limestone and basalt, rising almost directly from the lake, and, being partly below sea level and facing east, has a

climate unfavourable for vegetation. The destruction of the scrub cover having recently been completed, each heavy rain brings down a flood from the limestone and a mudflow from the basalt. Serious losses of property and some lives were caused in 1933 and 1934, and each year considerable sums are spent in clearing gravel, mud and rocks from the lakeside road. Reforestation has been commenced mainly with scrub species on the patches of land under Government control, and proposals for the acquisition and revegetation of the whole slope are under consideration.

"Similar work has been commenced on the steep rocky slope south of Nazareth, where floods cause considerable losses in the fertile plain of Esdraelon. Ruined valleys to the east and west of Nablus in the Samaria Hills are being studied with a view to action as soon as financial and political conditions permit.

"The spectacular floods in Syria which recently caused numerous deaths and great loss of property will not be without result if they awaken Governments and peoples to the need for action to combat erosion. They were caused by the disgracefully bare condition of the eastern slopes of the Anti-Lebanon mountains."

According to the Report of the Palestine Royal Commission, "the fact has to be faced that there are to-day no real forests in Palestine and that if there is one country in the world in which afforestation is desirable that country is Palestine" (2). There are only 76 square miles of scrub forest and plantations, out of some 6,250 sq. miles fit for cultivation or afforestation, and of the total land area of 10,400 sq. miles. In addition to this 76 sq. miles there are a further 450 sq. miles which retain some forest characteristics, but which have been ruined by overgrazing, overcutting and other misuse.

In ancient times the hills were protected by forests, but deforestation, shifting cultivation and soil denudation have produced barren rocky hills, from which the soil that remains is being washed away by rainstorms. Overgrazing prevents the growth of any protective vegetation, while in the plains the absence of trees and vegetation permits the advance of coastal sand dunes.

Early work on reforestation (particularly on those sand dune areas) and the creation of forest reserves led to the formation in 1935 of a separate Department of Forests.

The Royal Commission mentions the proposals of the Conservator of Forests and of the Forestry Officer of the Jewish National Fund; the former recommends that lands under the control of his department should be divided into three categories, forest lands (390 sq. miles), fodder land (similar area) and protected lands (97 sq. miles, which should be terraced and planted with fruit trees). The latter considers that 97½ sq. miles of sand dunes and 780 sq. miles in the hill country can and should be reforested. Only a little over 12 sq. miles have been reforested since the Great War, but it is considered that at least 15½ sq. miles should be planted every year with 6,500,000 forest and carob trees, the fruit of the latter being for forage purposes.

The Royal Commission fully realizes " the desirability of afforestation on a large scale and the advisability of a long term policy on the subject." In view of the scarcity of suitable land in the hills for the agricultural population it cannot recommend, however, " a policy which involves expropriation of cultivators on a large scale unless and until other cultivable land or satisfactory employment on the land can be found for them." The Commission does not doubt that in the aggregate there is a very large amount of land for afforestation but not for cultivation and in any case it strongly endorses the policy of :—

(1) afforestation of steep hillsides to prevent erosion,
(2) the prevention of grazing on land fit for afforestation, and
(3) where practicable, the establishment of village forests for the benefit of the neighbouring cultivators.

Stockdale (1) reports on a visit to Palestine and Trans-Jordan made in 1935. Further agricultural development in Palestine is very largely dependent upon securing additional, and upon improving available water supplies, which will, it is considered, have to be secured from underground sources provided the extent of this supply is ascertained.

Natural herbage quickly becomes re-established in Palestine, and within a few years shrub growth is to be seen on what was previously bare hillside.

As far as development is concerned, Stockdale states that additional reforestation is the requirement next in importance to the regulation of irrigation schemes and the discovery of additional water supplies. The most promising trees include *Acacia cyanophylla* (which forms an early ground cover), *Pinus halepensis* and *P. pinea*, while the carob, *Eucalyptus* and *Casuarina equisetifolia* are suitable in certain districts. Controlled grazing within the forest reserve will be necessary.

The results of erosion are very clearly seen in Palestine, the central hill range having been reduced through the process of time to bare and largely barren rocky slopes. The lands of the plains are in no small degree derived from washings from the hills ; during the rainy season the sea along the coast is frequently discoloured by soil from the Palestine hills and plains (1).

Not enough stone terraces are used in the vineyards and fruit gardens in the hills, while the loss that can be caused on the gentle slopes in the plains has not been realized.

Little can now be done to repair all the damage which has been caused in the hilly areas ; much can yet be done by reforestation in certain areas, while particular attention is recommended in connexion with the construction of terraces and contour drains, and in the cultivation of weed-free crops such as citrus and other fruits in the plains.

References (Palestine)

(1) England and Wales, Colonial Advisory Council of Agriculture and Animal Health. C.A.C. 247. Report by Mr. F. A. Stockdale on his visit to Palestine and Trans-Jordan. 1935. London, 1935. pp. 86.

(2) England, Palestine Royal Commission Report. Cmd. 5479. Presented by the Secretary of State for the Colonies to Parliament, July, 1937. London, 1937. pp. 404. maps.

Union of Soviet Socialist Republics

No detailed survey of eroded land in the Soviet Union has been made, but the available data and reports show that erosion is fairly extensive and increasing, although it has not reached the same catastrophic proportions as in the United States. Kornev (8) states that gully erosion has been known and commented upon for a long time, but owing partly to indifference and partly to ignorance of its cause, no adequate steps were taken to control or study it until a few years ago. The position in feudal Russia before the liberation of the serfs (1861) seems to have been comparable to that in America when the possibilities of agricultural mechanization were realized. The landowners' aim was to get the maximum out of the soil in the shortest time with the least expenditure on labour and improvements. During this period, sheet erosion was extensive, though generally unnoticed and not associated with the new gullies that continued to break up the land. Fortunately for Russia, too, the agricultural "tempo" was much slower than in twentieth-century America. The subsequent growth of a free peasant class, possessing mainly the poorer, sheet-eroded lands and working in direct competition with the large landowners, accelerated erosion further, and as the soils were exhausted or destroyed, cultivaton extended onto steep slopes and forest-covered watersheds. The peasants were powerless against the economic and natural forces confronting them, and their influence on the soil was mainly destructive. Neither did the first agricultural developments after the socialist revolution produce any better effects. The peasants retained individual ownership, the larger holdings being "liquidated" and the land re-divided on apparently the most equitable basis—namely, in narrow strips running up and down the slopes, and highly conducive to rapid gully erosion. "At the present time there are huge regions in the U.S.S.R. where, owing to excessive breaking-up of the topography, whole territories formerly under profitable agriculture are now occupied by immense ravines and infertile wastes" (8). This gullying is particularly widespread in the Dnieper basin in the Ukraine.

According to Kornev, collectivization was indispensable before adequate erosion-control measures could be considered. Collectivization has greatly facilitated the adoption of regional measures for erosion control but at the same time has been accompanied by a huge increase in agricultural mechanization. It is difficult to ascertain whether the authorities are fully alive to the dangers as well as to the merits of mechanization. The tractor plough is the enemy of grassland in semi-arid regions, but has been a much used and almost indispensable weapon to the propagandist, without whom the modernization and collectivization of Russian agriculture would not have been accomplished. The Soviet Union, however, has been

forewarned by the disasters that have overtaken other countries and it has inherited from the imperial era a scientific tradition in pedology with an exceptionally deep insight into fundamental causes. Pankov (14) regards soil erosion as a new natural phenomenon, created by human intervention, in the process of denudation. It is an inevitable and active factor in the cultural landscape and in the contemporary history of the earth, but capable of being regulated and controlled by the agency that brought it into being. He proposes using the term erosion to include related destructive processes, such as leaching and soil exhaustion, which are accelerated by human action, leaching being, in effect, erosion in solution. Predominant over all other factors influencing erosion are the cultural history of the land and the prevailing social conditions (13).

The first important step in the study of erosion was taken in 1921 by the foundation of the Novosil Experimental Ravine Station in the Kursk forest-steppe region, some 300 miles south of Moscow, where erosion has been exceptionally severe (10). The Station based its work in the first instance on the findings of the Tula Hydrographic Expedition (1908) which emphasized, apparently for the first time in Russia, the distinction beween the ancient, post-Tertiary erosion that shaped the natural valleys and ravines, and contemporary gully erosion produced by human activity. The Tula Expedition showed that natural drainage systems were definite functions of the size of the catchment areas, their relief and geological structure, and were perfectly adapted to cope with all the natural run-off. Excessive run-off and gully formation were phenomena that had only appeared since human settlement.

Thus the first serious studies on erosion in the U.S.S.R. were directed towards elucidating the genesis and history of man-made gullies. Investigation of heavily gullied catchment areas brought to light the now well-established fact that roads, ditches and other artificial inequalities in the land tended to collect run-off and form foci from which gully formation might start. This was a strong point in favour of abandoning the prevalent small-field, individual farming for collectivization (10). Further investigation showed the close connexion between gully formation and the hitherto unobserved sheet erosion which had occurred extensively on cultivated slopes with gradients of 3 per cent or more. Erosion was usually greatest at the bottom of slopes, owing to the particularly heavy run-off (90 per cent) of thawing snow overlying frozen soil causing torrents and floods in the canals and ditches bordering cultivated fields. From the bottom, erosion spread with gradually decreasing intensity to the watershed.

These observations drew attention away from gully formation to its more serious and fundamental cause, sheet erosion, and the relation of the latter to agricultural organization. At present, the Novosil Station—the principal erosion station in the U.S.S.R.—bases its studies on erosion control on the following facts: (1) a catchment area is the smallest unit to be covered by adequate control measures; (2) the artificial drainage

system resulting from agricultural operations must, like the natural system, be adapted to the nature of the catchment area ; (3) agriculture must be organized to fulfil as far as possible these latter requirements. Without collective farming this would have been impossible. What may be described as the official view seems to be that erosion is a social-political phenomemon, and its control a problem in regional hydrology.

Except for the region—the central part of the Central Russian plateau —surveyed by the Tula Expedition, no accurate data showing the present extent of erosion in the Soviet Union are available. The Tula Expedition showed that 63-75 per cent of the area studied was cultivated on slopes and therefore liable to be, if not already, eroded, 10-18 per cent was completely ruined by gullying and erosion, and the rest occupied by rivers, river banks, ravines etc. Kornev (8) gives the following tentative figures for the percentage areas of parts of European Russia, topographically liable to gully erosion.

Central Russian plateau	60-70	per	cent.
Cis-Dnieper elevated land	75-80	„	„
Right bank of Volga	45-50	„	„

Pankov (15) states that typical annual losses by erosion in the podzol zones are 2-3 tons of soil per hectare, in the steppe region 5-9 tons, and in the sub-tropics 20-50 tons. One of the worst eroded areas, by reason of its steep and broken relief, is the south-western normal chernozem region, where probably 500,000 dessiatins (1,350,000 acres) of fertile land have been destroyed in the last 2-300 years. The following figures showing changes in land utilization during the period 1861-1901, throughout an area for which accurate figures are available, indicate a rapid deterioration of the soil.

	Increase (+) or decrease (—) in dessiatins
Estate lands	+5283.3
Ploughed land	—7847.1
Meadow	—4517.8
Hay	—1258.0
Pasture	— 702.0
Forest	—7699.8
Shrub	+5288.6
Land unsuitable for agriculture	+8175.7

The exact meaning of " estate lands" is not clear ; presumably they refer to parks and similar areas not falling into the other categories. The unsuitable land (of which about 40 per cent consisted of gullies) had increased at the expense of former arable land, overgrazed pastures and ploughed-up hay fields which to some extent had been replaced by clearing the forest. Pankov states that this area is typical of many ; it illustrates how the process of soil destruction, starting on the most fertile fields, spread through the grassland to the forest. The predisposing cause seems to have been land hunger.

The steppe region appears to have suffered most, perhaps on account of its great natural fertility, but very serious erosion has also been reported from the Trans-Caucasian and sub-tropical regions, particularly on plantation (e.g. tea and tobacco) land. In the podzol zone to the north of the steppe and forest-steppe regions, extensive erosion has occurred on cultivated and de-forested lands. In writing of this zone, workers lay less emphasis on gully formation (except in mountainous districts), but sheet erosion is very prevalent although often only detected by chemical analysis of the soil profile (5). At present, erosion in the cultivated podzol zone appears to have caused great losses in fertility, but relatively little complete soil destruction or land abandonment, as in the chernozem zone. Makarov's " Agricultural Map of the U.S.S.R." (12) shows that the area of intensive cultivation in European Russia coincides with the chernozem zone; in other soil zones, cultivation is very spasmodic. In the Ukraine 51.4 per cent of the whole area was under sown crops, and in White Russia, 23.1 per cent. A survey of the available Russian literature leaves the impression that erosion as an imminent menace is mainly confined to the intensively cultivated chernozem zone, although it is prevalent and increasing, in milder forms, over much larger regions, particularly in the " chestnut-soil" areas which correspond ecologically with the short-grass country of North America. There are no reliable data for Asiatic S.S.R., but assuming that serious erosion is associated with intensive cultivation, it is probably not very widespread.

Owing partly to the Russian scientific outlook, erosion research in the Soviet Union started on general, and is only now approaching particular problems. Led by the late Professor A. M. Pankov, the subject has been studied from the historical point of view, with special reference to the influence of recent (19th and 20th century) developments in Russian agriculture. Erosion is regarded as the natural consequence of the human factor in soil genesis, comparable to the effects of the climatic, geological and vegetation factors, from which it is inseparable, and consequently it has been studied primarily in its relation to the evolution of the principal genetic soil types—podzol, chernozem, red soils, etc. The soil properties studied in relation to erodibility have been those inherent in the genetic type, namely structure, profile characters and the nature of the absorbing complex. References in Russian literature to texture, permeability, etc. in relation to erodibility are mainly to American work.

Vilensky (18) pointed out that a soil's resistance to erosion is a direct function of its whole structural stability which depends partly on the nature of the compound aggregates and partly on the binding forces between them. He showed that the size, degree and rate of slaking, and water-stability of natural soil aggregates were related to erodibility determined both in the laboratory and in the field. Vilensky's results are admittedly only preliminary and are insufficient to draw conclusions as to the soil structure most resistant to erosion, but numerous observations both in Russia and elsewhere have led to the conviction that the crumb (chernozem)

structure is the most desirable and most capable of being preserved by suitable agricultural practices. Voznesensky (see 4) has proposed a formula for the "index of erodibility" which includes the silica-sesquioxide ratio of the soil and an "index of aggregation." The index of erodibility, E_1, is related to Middleton's erosion ratio, ER, (p. 142) as follows :—

$$E_1 = \frac{Er}{a}$$

where r is the silica-sesquioxide ratio, and a the index of aggregation.

A. A. Lazarev (11) has made an exhaustive study of the properties of degraded (forest-steppe) chernozems in the virgin state, and under cultivation and grass fallow. Although essentially a fertility study, many of the findings, which are summarized below, have a bearing on the problem of erosion control.

(1) In the ploughed horizon of cultivated soils, there was a marked decrease in the size and stability of the structural aggregates. The humus horizon increased in depth and became less sharply differentiated from the underlying horizon, but contained much less humus and nitrogen than in uncultivated soils. The reduction was most marked in the water-soluble humus.

(2) Maximum hygroscopic moisture was higher in cultivated soils than in virgin soils, with the grass fallow intermediate. The order was reversed, however, in the subsoils.

(3) Total phosphate was low, but available phosphate was high in cultivated soils.

(4) Cultivation reduced the amounts of absorbed bases (Ca and Mg), but had little effect on reaction, presumably due to the simultaneous oxidation or leaching of humic acids.

(5) Microbiological activity and nitrification were greatest in cultivated soils ; denitrification was most complete in virgin and fallowed soils.

(6) Qualitatively, the changes produced by cultivation might be described as one-sided, causing a possible initial increase in productivity, but leading to rapid exhaustion and structural deterioration.

The grass-fallowed soils were similar in structure to the virgin soils, and Lazarev recommended an occasional return to grass as a ready means for maintaining soil structure.

On the other hand, Gladilovich and Lebedeva (2) found that cultivation of strongly podzolized forest soils (Leningrad district) increased the aggregate structure, the available nutrients and the degree of base saturation.

The theories of Prof. W. R. Williams (Timiriasev Academy, Moscow) on the importance of grassland in maintaining soil structure have recently come into considerable prominence in connexion with erosion control. Before erosion became a serious scientific study in the Soviet Union, Williams propounded a hypothesis that the decay of past civilizations was due to a decline in soil fertility consequent on the destruction of the soil's

crumb structure when the rising demands of civilization necessitated the wholesale ploughing-up of grassland. Williams regards grass as the soil's principal weapon against human depradation, although under certain circumstances (e.g. wet meadows and some grassed forest soils) man can improve the natural soil structure by proper cultivation. Grass is the basis of all conservative agricultural land utilization, and Williams worked out systems of grass rotations, fertilizing and cultural measures appropriate to the principal regions in the Soviet Union. His views are frequently quoted in works on soil erosion and appear to be exerting a marked influence on conservation policy. Williams was particularly concerned to show how his proposals harmonized with the evolution of the socialist state, but they are now assuming a practical importance that transcends or complements their political significance. There can be little doubt that, in the future, grass will occupy a more important position than hitherto in Russian agriculture. There is, furthermore, an urgent need to stimulate animal husbandry in order to re-coup the catastrophic reduction in livestock that occurred during the war years. At the present time overgrazing, which was probably common on the former peasant holdings, does not seem to be attracting much attention.

Several Russian investigations have shown that perennial grasses will produce a stable structure, with a great increase in permeability persisting for some years after subsequent ploughing, on all the major Russian soil types (16). In the turf podzol regions, the structure deteriorates rapidly after cultivation, but if deterioration has not gone too far, the structure can usually be restored in two years by sowing and fertilizing perennial grasses (17). Short rotations, including two years under sod, are therefore advisable, whereas in the chernozem region longer rotations up to six years or more may be used. Kononova (6) states that clover, in a six-course rotation, is the main cause of the increased resistance to erosion. The consequent humus accumulation and improved soil conditions are, however, transitory and disappear in the course of the complete rotation. In his opinion, a six-course rotation should include at least two years under a dense turf cover (grass and legumes) so as to produce a permanent accumulation of organic matter and a stable crumb structure.

As regards profile characteristics in relation to erosion, the general problem is being approached from both ends, namely, the effect of erosion and denudation on profile development and the effect of profile characteristics on erodibility. Gerasimov (1) has pointed out that normal denudation operates to keep the most mobile weathering products near the soil surface; simultaneously with the downward leaching of these products the surface layers are removed, and in cases of accelerated erosion the apparent paradox will arise of the least mobile weathering products being lost (by erosion) more rapidly than the most mobile (by leaching). The latter, e.g. salts under dry alkaline, and sesquioxides under moist acid weathering conditions, accumulated at a certain depth in the profile during soil formation, will thus re-appear at the surface. Gerasimov offers this

hypothesis as a partial explanation of the present salinity and alkalinity of dry-steppe soils, and the occurrence in moist regions of relict allite deposits, represented by the characteristic podzol-laterite process in the south and by bog formation with hard-pan in the north.

Gussak's (3, 4) work at the Transcaucasian (Tiflis) Research Institute of Water Economy illustrates how profile characters are studied in relation to erodibility. Gussak used soil monoliths with undisturbed structure, 100 × 40 cm. in area and 0.5 cm. deep, and arranged them on slopes of 5, 10, 20 and 30 degrees exposed to the natural rainfall. Different profile layers were studied by taking the monoliths from different depths. Percolation, run-off and erosion were measures by means of receptacles attached to the lower ends of the monoliths. Ten deluvial sub-tropical red soils from an ancient terrace and ten eluvial soils from steep slopes were studied. The annual rainfall of the region was 2,500—2,800 mm.

A striking difference was observed in the erodibilities of the deluvial and eluvial soils, run-off from the former being about twice that from the latter. Erosion was also greater from the deluvial soils, as shown by the following figures giving the mean weight in grammes of soil eroded from monoliths exposing the A, B and C horizons.

Slope	5°	10°	20°	30°
Deluvial	49.3	91.6	122.7	145.9
Eluvial	19.8	52.7	69.5	87.8

These observations have a general practical significance, since the greater erodibility of deluvial soils to a large extent offsets their more favourable location on gentle slopes and in plains. The two soil varieties differed also in regard to the relative erodibilities of their genetic horizons ; in the deluvial series, the A and B_2 horizons eroded about twice as quickly as the B_1, whereas in the eluvial series, the surface (A_1) horizon eroded least, the rate of erosion increasing with depth. These facts were taken to indicate that the steeply sloping eluvial soils acquire natural erosion-resisting properties. Gussak found that for sub-tropical red soils run-off varied as (angle of slope)$^{\frac{1}{2}}$ and erosion as (angle of slope)$^{\frac{1}{2 \cdot 5}}$ for slopes up to 30°.

A rough calculation showed that average soil losses of 20 tons per hectare per annum on gentle to moderate slopes, and 50 tons on steep slopes were taking place under plantation agriculture (tea, tobacco, citrus) and that these would result in the complete removal of the surface humus horizon in from 10 to 20 years.

Particular attention has been paid by the Novosil Station to the ' brosovie zemli," the nearest English equivalent of which is "spent lands." Spent lands are badly eroded areas adjoining water courses and occurring on the bottom third of eroding slopes. The former surface soil horizon has usually disappeared more or less completely, and the spent areas are

interspersed with frequent hollows and gullies. They carry a very poor natural vegetation and are practically useless for agriculture as they exist at present. Their origin is attributed to the former system of individual small-scale agriculture under which the lower slopes were the most intensively cultivated. The hollows and gullies originated from the many fences and ditches separating the fields which, moreover, were cultivated up and down the slopes. Kornev (9) estimates that there are about 5 million acres of spent lands in European Russia.

The significance of the spent lands lies not so much in their uselessness as in their destructiveness. They act as foci from which erosion spreads, both in length and breadth, at an alarming rate. Lying at the bottom, and often on the steepest part of slopes, they receive the full destructive force of the run-off from above, the old gullies increase in size and produce new vertical denudation, destroying the vegetation, increasing the mean gradient of the upper slopes, and making the land less and less resistant to erosion. Furthermore, the abandonment of spent lands results in the cultivation of less suitable areas lying above them. Kornev (9) regards spent lands as the main causative factor of the spread and acceleration of sheet and gully erosion in the catchment areas where they occur.

The reclamation of spent lands is thus a fundamental problem in erosion control. Treatment consists in bringing them back to a condition in which they can support a vegetation dense enough to prevent further erosion both on themselves and on neighbouring areas. Investigation of the properties characteristic of spent soils has suggested a procedure for their improvement that promises well.

One of the most noticeable characteristics of spent soils is their poverty in humus and nitrogen. Where spent soils occur, these constituents decrease regularly from the watershed to the bottom of the slope, while the amount of erosion increases. Kononova (6) gives the following data, typical for much of the Novosil region.

Organic content of soils on a slope

(Grey forest soil on loess clay, under oats. Mean slope 5 per cent)

Distance from watershed (metres)	C %	Humus %	N %
100	1.84	3.16	0.16
200	1.64	2.82	—
500	1.41	2.43	—
600	1.17	2.01	0.12
700	0.83	1.43	0.08

Owing to excessive erosion, the humus horizon of spent soils is very thin (normally 8-10 cm.). The soils, however, are far from "dead." Microbiological studies by Cholodny's method have shown that, under optimum moisture conditions, they develop a very rich bacterial flora and a somewhat less rich fungal flora. The principal need of the soils is for

nitrogen, to which they respond in a quite remarkable degree "levelling out the yield-depressing effect of a slope throughout its length." (7). Potash and phosphate have little effect. Kornev (9) obtained the following yields (centners per hectare) of oats on spent soil fertilized with 60 kg. N, 100 kg. P_2O_5 and 96 kg. K_2O per hectare.

Fertilizer	Grain	Straw	Total	Total relative to control
O	0.31	3.30	3.61	100
K	0.61	4.51	5.12	142
P	0.59	3.74	4.33	120
N	3.92	23.32	27.24	757
PK	0.65	3.38	4.03	112
NK	4.94	25.98	30.83	856
NP	5.83	29.39	35.12	974
NPK	6.79	32.54	39.33	1089

These results show that one application of nitrogen is sufficient to convert spent lands into fertile fields supporting a rich vegetation. Nitrogen makes cereal culture a paying proposition, but this by itself does not solve the erosion problem. Erosion control consists in maintaining the vegetation and regulating it to obtain the optimum effect on soil structure and humus and nitrogen content, and can apparently be achieved by adopting a 6-course rotation including two years under leguminous sod, fertilized as required, and four under cereals. As a general rule, one year under leguminous sod improves the nitrogen régime for the following crop, but has an insufficient effect on soil structure ; two years under sod maintains a good structure throughout the rotation. It is believed that the adoption of this type of rotation would go far towards completely reclaiming the regions where spent lands occur, and would indirectly benefit the whole country by developing animal husbandry and by inducing the cultivators to look beyond their immediate profits.

As a preliminary to formulating a comprehensive programme for erosion investigation and control, the erosion laboratory of the Soil Institute of the Academy of Science issued in 1936 the following questionnaire to agricultural authorities, civil engineers, experiment stations, sovkhozes, kolkhozes, etc.*.

(1) Show on what soils and under what conditions of relief and aspects, gullying, sheet erosion, land slides and soil drift occur. (Describe slopes as steep, gentle, etc. ; north, south etc. ; long or short ; parts of slopes—middle, top, bottom).

(2) With what is soil wash and soil drift connected—size and character of the catchment area, the character of the relief, parent rocks, elevation, precipitation (torrential rain, ordinary rain), character of winter

**Erozia Pochv*, 1937, pp. 353-354.

precipitation, spring floods, time, methods and type of soil cultivation, crops, deforestation, pasturage of cattle, irrational land utilization, predatory individual husbandry etc? In the case of soil drift show times, strength and direction of winds and their duration.

(3) Time of occurrence (season, month) of different types of erosion, and their frequency during the season or month (it is desirable to give quantitative expression, approximate volume or thickness of eroded layer).

(4) Their development and cessation in pre- and post-revolution periods, and possible reasons.

(5) What causes in your opinion have brought about differences in intensity and rapidity of development of these phenomena on the same soils (e.g. pulverizing the arable layer, monoculture [state which], moisture of the arable layer, depth of ploughing, character of the soil surface, its vegetative cover, crop, direction of slope, furrows, roads, etc.) ?

(6) How do these phenomena affect the yields of crops (mention which crops—grain, straw or hay) and what effect have they on the character and properties of soils, soil fertility and subsequent cultivation, soil moisture, reaction, land utilization, silting of meadows, rivers, destruction of pastures, character of snow water, the amount of water in rivers and brooks, disappearance of springs, roads, transport, amount of precipitation etc ?

Does soil wash affect the formation of gullies and increase soil drift ? How quickly is it taking place ?

(7) Describe the effect of this phenomenon on the heterogeneity of arable land and crop yields, on the amount of washed-out seed, and on the response to applied fertilizers.

(8) How are eroded and wind-blown soils utilized ? Results of utilization. Areas of soils undergoing different kinds of erosion (percentage of total area), and the annual percentage increase.

(9) Do you consider the different forms of erosion in your region as a disaster which it is necessary to combat and what methods of control are in force ? Are they sufficient, and what methods do you consider to be the best in your district under different conditions ?

(10) Do you consider that there are any positive aspects of the consequences of erosion and what are they (e.g. the formation of market-garden soils on washed areas, drainage of the area, etc.) ?

(11) Do you consider necessary the immediate investigation of the different forms of erosion, their causes and consequences and the development of methods of control ?

References (U.S.S.R.)

1. Gerasimov, I. P. [Denudation and soil development]. *Erozia Pochv*, 69-75. 1937.
2. Gladilovich, B. R. and Lebedeva, A. F. [Influence of cultural tillage on the process of soil formation]. *Pedology*. No. 6, 859-69. 1936.
3. Gussak, V. B. [Experimental study of sheet erosion and run-off on red soils in the wet sub-tropics.] *Pedology*. No. 1, 35-56. 1935.

4. ———— [Factors and intrinsic results of surface erosion of red soils under moist sub-tropical conditions in Georgia.] *Erozia Pochv*, 103-54. 1937.
5. KASATKIN, V. G. [Soil erosion in podzolized zones.] *Erozia Pochv*, 21-33. 1937.
6. KONONOVA, M. M. [Methods for increasing organic matter in the spent lands of eroded regions.] *Erozia Pochv*, 259-72. 1937.
7. KORNEV, Y. V. [The problem of manuring eroded slopes.] *Khim. Sotsial. Zemled.* No. 4. 12-9. 1935.
8. ———— [Soil erosion as a factor in yields.] *Erozia Pochv*, 189-246. 1937.
9. ———— [The utilization of eroded upper slopes in relation to certain erosion factors.] *Erozia Pochv*, 273-94. 1937.
10. KOZMENKO, A. S. [Work of the Novosilsky experiment station for studying methods in the control of erosion.] *Erozia Pochv*, 155-85. 1937.
11. LAZAREV, A. A. [The influence of cultivation on the properties of chernozems in the forest steppe regions.] *Akad. Nauk. SOPS.* pp. 70. 1936.
12. MAKAROV, I. F. The agricultural map of U.S.S.R. Leningrad, pp. 91. 1926.
13. PANKOV, A. M. Present state of the problem of the yielding of soils to erosion. *Studies in the Genesis and Geography of Soils, Dokuchaiev Soil Inst.* 229-53. 1935.
14. ———— [Normal denudation and soil erosion]. *Erozia Pochv*, 8-19. 1937.
15. ———— [Soil erosion in the southern part of the central chernozem zone.] *Erozia Pochv*, 303-14. 1937.
16. ROSTOVTSEVA, O. S. and AVAEVA, M. I. [The role of perennial grasses in the formation of compact soil structure.] *Pedology*. No. 5/6, 797-814. 1935.
17. SAVVINOV, N. I. [The effect of perennial grasses and certain agrotechnical methods on the stability of soil structure in different zones.] *Trans. Soviet Sect. Int. Soc. Soil Sci.* 5. 58-102. 1936.
18. VILENSKY, D. G. [The technique of the investigation of soil tenacity in soil erosion studies.] *Pedology*. No. 5/6, 789-96. 1935.

India

At the first meeting of the Crops and Soils Wing of the Board of Agriculture and Animal Husbandry in 1935 (8) the Committee on soil amelioration stated that " the control and prevention of soil erosion is of particular importance in parts of Madras, the Bombay Deccan, the United Provinces, Punjab, Central Provinces, Chota Nagpur and Central India." In general, erosion would be expected to occur throughout the monsoon regions comprising much of the above States and numerous native States as well. While the local causes of erosion are necessarily diverse, the most potent and common are deforestation, overgrazing, and cultivation on unterraced slopes. Deforestation and increases of population have both been enormously accelerated since British occupation, and to-day parts of India present a picture of man-made desolation without parallel except perhaps in China. " The human population of India is increasing at the rate of about three millions per annum. Much of this increase is occurring in the tracts where nature in the first place provided easy conditions for human settlements, namely, a rainfall not too heavy for the ordinary farm crops, and natural grasslands in which cattle thrive and remain healthy. Within the heavy rainfall areas further east, the regrowth of dense tropical jungle and conditions inimical for livestock have discouraged dense settlement. Therefore much of the weight of this increasing population is falling upon the *tension belt* where grassland can persist only under reasonable treatment, and, if once destroyed, cannot reinstate itself as easily as it can under a slightly heavier or better distributed rainfall. Hence over very large tracts of country, natural grasslands have already disappeared and village livestock are dependent upon bush and tree growth for their day to day existence. In most other countries livestock are maintained on a ration of grass, and the bush growth which occurs in the grazing grounds is looked upon as a natural reserve which should be used only in times of acute scarcity ; in much of India the last vestiges of shrub growth already form the ordinary daily ration for the village herd. The amount of erosion caused directly through this state of affairs has to be seen to be believed " (4).

The most serious erosion is evident among the Indian foothills and their outlying slopes, where gullies and floods are devastating huge areas. The observations of Wad and Tambe (13) on the high erodibility under a monsoon rainfall of black cotton soils at Indore suggest that erosion may be very extensive over the vast areas in Central India, the Central Provinces, Hyderabad and Bombay, covered by these usually deep and fertile soils. Howard (7) also drew attention to the extensive erosion occurring in Central India and elsewhere, but considered that it was probably more serious on the light soils in Peninsular India than on the heavy black cotton

soils. Ayyangar and Krishna Rao (1) state that in Madras, particularly in the region affected by the monsoon, erosion is a serious economic evil, but no steps have been taken either to assess the loss to the Province by erosion or to combat it. Mann (10) drew attention to the serious erosion on black soils underlain by impermeable subsoils in the Raichur district, Hyderabad, the loss of effective rainfall caused thereby, and its relation to the frequently recurring famines. Tea estates have in the past suffered considerably, but terracing is common on sloping estates, and clean weeding has not been practised so rigorously in India as in Ceylon. The Committee on soil amelioration already referred to (8) considered that the importance of checking erosion was fully appreciated by the organized planting industries, but constant attention and propaganda were needed to ensure that all hill tracts deforested for plantations should be terraced immediately. Extensive and successful bunding schemes have been carried out in the Bombay and Madras Deccans and in Central India, though recently they have been stopped owing to financial stringency. In many parts of India, indeed, the high cost of loans and the impossibility of getting any immediate economic return from reclaiming very poor and badly eroded land is seriously impeding soil conservation work. " Self-help " projects on a community basis in the villages appear to be the most hopeful solution for farm lands.

Jacob (9) states that erosion caused by deforestation is severe in North Bengal and Assam. The outer hills of the Eastern Himalayas and the ranges south of the Brahmaputra were only a few years ago covered with dense forest. The rainfall varies from 70-200 inches, mostly falling between June and October. The *taungya* system of shifting cultivation (felling a hillside, burning, cropping for 2-3 years and leaving for 30-40 years) has been practised for centuries, and the long rest enabled the land to recover as tree growth is rapid. Owing to disease and feuds, there was always sufficient land for the population without undue pressure on the forests. The result of British rule has been to increase the population and correspondingly to reduce the rest period. The consequent erosion has reduced stream flow, and shortage of water has forced the villagers to make new villages on hitherto virgin land. The main rivers in the plains are now frequently in a state of violent flood. " In many parts of East India the extent of new shifting cultivation has to be seen to be believed ; during the day there is a thick canopy of smoke over the whole country, while at night, looking up to the hills from the plains, the lights of fires can be seen as far as the eye can reach." Recent large immigrations from Nepal into Bhutan have resulted in the deforestation of a great area of the outer Himalayas with a monsoon rainfall up to 250 inches, and a very serious increase of floods in North Bengal. In many parts denudation by faulty cultivation and " jhuming " has been intensified by excessive grazing of buffaloes, cattle, goats and sheep, particularly in the Punjab and United Provinces. The worst results of torrent damage have occurred in the more fertile land at low elevations,

where the destruction spreading from the banks of the rivers and streams has contributed to erosion.

Burma has suffered, but the vast areas of forest still existing has prevented the damage from spreading widely. Here, and to a lesser extent in Bengal, Assam and the United Provinces, *taungya* has been adopted for afforestation purposes. The cultivators are made to sow or plant useful trees in rows between their crops, but they generally regard the trees as a nuisance and take little care of them unless constant supervision is exercised.

In the United Provinces, shifting cultivation has practically been stopped, but in Burma, Bengal and Assam little has been done to check it. The Darjeeling Hillsides and Rivers Conservation Bill (1918) empowered the Deputy Commissioner to regulate the use of private lands that were being denuded of forest, but it is not known to what extent these powers have been utilized. Elsewhere little or no anti-erosion legislation has been introduced.

No remedy is likely to succeed without careful education and instruction of the Indian cultivators in better farming, particularly terracing, and in the care and feeding of cattle. Practical demonstration would involve very considerable financial assistance from governments. On the other hand, the proper control of grazing grounds, and the encouragement of sound fodder practices, leading eventually to the numerical limitation of cattle, can be developed and encouraged by a relatively small staff of officers with practical farming knowledge and some gift for this form of publicity work. This has already been taken up in the Punjab (see below) and has cost government little more than the pay of the officers so employed.

Control in the less accessible areas is difficult owing to the Government's aversion to interfere with hill tribes occupying the main catchment areas. Some catchments are in native States, under a varying intensity of political control. "At present grazing grounds in most parts of India are a mockery, devoid of nutriment, and often hot-beds of infectious disease."

Gorrie (5) also agrees that the hill grazier is the Punjab's worst enemy, though the extension of potato growing and a general lack of efficient terracing for all crops except rice are also largely responsible for damage. About 35,000 square miles of the lower Western Himalayan foothills are affected, of which the Punjab Forest Department controls about 5,000 square miles, and most of the rest is heavily overgrazed and quite unprotected. Closure to grazing is the only feasible remedy at present, but other lines of attack aiming at better farming practices might be opened out by more active co-operation between the many governmental departments concerned.

Hamilton (6) has given a detailed account of erosion in parts of the Punjab Siwaliks. This range of hills skirts the Himalayas for 1,600 miles from the Indus to the Brahmaputra. The rocks are mainly unconsolidated pebbly rocks and sands. In the United Provinces, east of the Jumna

River, a sound forest policy has checked erosion, but in the adjoining Punjab it is bad, due to deforestation during the last 80-90 years. The damage has mainly been caused by torrents (*chos*), formed by gully erosion, that sweep down from the southern slopes during the monsoon.

The *cho* is characterized by the steepness of its gradient and the violence and irregularity of its discharge. The torrent carries much suspended material which is deposited on the less steep lower slopes in a characteristic detrital cone which continually increases in radius and width.

The behaviour of the flood and the damage it inflicts depend on the lie of the land, the soil, the amount of suspended sediment, the velocity and the ultimate destination of the torrent. If the torrent can make a definite channel which it can deepen, little damage is done. The usual loose soils favour spreading in the plains, and a steepening of slope, by gully formation, in the hills. The main drainage channels are fed by numerous precipitous side streams, giving to the channels catchment areas out of all proportion to the external features of the range. The *chos* debouching onto the cultivated sandy plains have long since silted up the original drainage channels formed when hill erosion started, and the floods are forced out over wide areas. The Hoshiarpur *cho* beds in the plains are broad rivers of sand with a very slight fall, wet only during flood periods. The conditions in their catchment areas are, moreover, most favourable to rapid run-off and erosion. The floods subside as suddenly as they start, and all the water is lost to the land. There are indications of a steady fall in the water table in the outlying plains below.

There is evidence that 100 years ago the *chos* ran between well defined banks, and in some places perennial streams that could be used for irrigation issued from the hills. Today, floods are the only source of water. Much of the subsequent erosion has been due to intensified exploitation that occurred when British rule secured some measure of prosperity and security. The acreage under *cho* beds at three successive settlements in the Hoshiarpur district were

1852	1884	1897
48,206	80,057	94,326

Since 1897, the rate of destruction of cultivated land has decreased, partly owing to a decrease in rainfall (i.e. from 34.45 inches in 1891-1900 to 26.61 inches in 1921-30, possibly due to deforestation), and some slight local protection of the Siwaliks, obtained by legislation. In all, probably 150,000 acres are either under *cho* beds or have been otherwise destroyed by erosion. Reclamation to a cultivable condition is extremely difficult.

Attempts to check *cho* damage in the plains by bunding have been unsuccessful, and it is generally admitted that conservation of the plant cover in the Siwalik catchments alone can afford relief by checking sheet erosion of the loose sandy soils at its source. At present, no provision has been made for reforestation, which at best would be a slow process. Encouragement of grass and closure to grazing over as wide an area as

possible are the most hopeful antidotes to sheet erosion, though they will not prevent it entirely. The chief obstacle is the thousands of Siwalik peasants who demand the use of the land, and consistently overgraze it. A closure effected by legislation in 1902 has brought great benefits to some villagers, who now make handsome profits from the sale of surplus cut grass, and it is hoped that this example will act as an educative influence. If once grass can be established, bush and forest will follow, and completely check erosion. Closure, stall feeding, and a proper system of pasture management, including manuring and green manuring, are the only practical means of starting to reclaim both the hill lands and the devastated plains which are more and more needed for the support of the increasing population.*

The Punjab Government has made a beginning towards introducing a sound land-utilization policy based on fodder production, but progress must necessarily be slow, since it involves a profound change in the whole life of the grazing communities (4). Three forest officers have been allocated in the worst eroded districts to obtain rotational grazing closures (with the consent of the villagers), to reserve hay fields and to institute general erosion- and torrent-control measures, as required by the circumstances. Constructive work, however, can only be done on a self-help basis of free labour, because the Government cannot afford to undertake it. Gorrie (4) suggests that fodder production for local livestock could be stimulated by the following measures.

(a) Rotational closures of grazing lands belonging either to individuals, village communities, or the Government. Much government land is so heavily burdened with rights as to be uncontrollable except by agreement.

(b) Partition of *shamilat*, by allocating the common grazing land to individuals to cultivate, or conserve for their own animals; this has been extraordinarily successful where there is a real scarcity of cultivated land.

(c) *Panchavat* or village committee management; in certain parts the delegation of authority to these committees has been most beneficial.

(d) Intensive improvement of natural grasslands, including "gully-plugging," to stop active erosion, and the application of the principle of *watt bandi* or contour ridging, so far applied only to farm crops, to the more gently sloping grasslands.

(e) Development of the tree fodder supply by distributing transplants of suitable tree species. The use of tree loppings for fodder is a feature of much Indian animal husbandry.

(f) Development of the use of green fodder crops and silage. In the poorer parts land cannot be spared for any crop that does not produce human food.

*See also "Report of the Punjab Erosion Committee, 1932" (Government Printer, Lahore, 1934).

(g) Research on the correct grazing incidence for local types of bush and grass; given stall feeding for the two hottest and driest months in the year and closure during the monsoon growing period, this incidence could actually be fairly high for the remaining months without causing excessive denudation.

(h) Restriction of immigrants and 'non-right-holders' livestock —a thorny problem.

(i) Reduction of local herds by encouraging castration of scrub bulls, and by propaganda and demonstration of "fewer and better cattle." The change to grass cutting would in itself be helpful because nobody will cut grass for animals which give no return in work or milk.

This last item, the reduction of surplus animals, should really be placed first, because if it is omitted the rest of the work would be largely useless. Where progress depends upon persuasion, however, so drastic a suggestion may do more harm than good by antagonizing the whole community.

Erosion is also very widespread in Kashmir, where it is directly connected with heavy goat grazing in the Jammu Siwaliks. Goat grazing clashes with sheep grazing on the higher elevations and causes deterioration of scrub forests on the lower hills. Taxation, rising with the number of goats kept, was introduced and proved valuable, but was abandoned for political reasons.

In the United Provinces, erosion is worst in the drainage area of the Jumna River which, unlike the Ganges and its tributaries, is a fast-moving river flowing through hilly and badly gullied country. The base level of the Jumna is well below the natural level of the soft-soil country through which it passes, and it is estimated that, as the accumulated result of flooding and scouring, its bed at Etawah has been lowered 60 feet in the last five centuries, with a corresponding fall of the spring level. The cold-weather level of the river is often 120-200 feet below the surrounding country (11). In the Etawah district alone, there are 120,000 acres of completely barren, gullied land along the banks of the rivers. The district is notable for some pioneer work, started in 1914, to reclaim the devastated land by afforestation. The objects of the work were to reclaim the gullies, to create fuel and fodder reserves for the villages, and to obtain a profitable return from the waste lands. The methods adopted would meet with general approval to-day. They included deep ploughing of the hard, baked soil to allow aeration and moisture penetration, contour ridging to hold up rain water alongside the tree seedlings, and the construction of dams at suitable intervals from the heads of the gullies downwards. "It is found by experience that as soon as grass and tree-growth is established, all run-off practically ceases. The fixing of sites for the dams requires considerable experience, the cheapest sites are usually the worst in practice, everything depends on the position of the waste water escape which

should be a natural one if possible." (2). Subsequent afforestation has been very successful, and when combined with rigidly controlled grazing has effectively checked erosion and brought some land back to productivity. The problem now is to create suitable organizations to ensure the application of the methods on a scale commensurate with the magnitude of the affected areas.

Garland (12) has emphasized the necessity for positive action rather than the mere cessation of grazing for checking erosion and reclaiming land in Bombay. In many places, erosion has progressed so far that revegetation with either forest or grass is negligible, or too slow to be of much use, when the land is closed to grazing. He describes an area at Poona, on the tension belt between thorn scrub and mixed deciduous forest with a rainfall of 24 inches, that after closure for forty years had only produced very inferior grasses and a few scrub trees, but by dividing a 40-acre area into four paddocks and grazing each as closely as possible before moving the cattle onto the next, it was possible, after five years, to maintain 20 cows on the area throughout the year. Good grasses had replaced the inferior ones, and in spite of the very heavy grazing, natural tree regeneration had begun and erosion had been checked. The land was in a condition in which it could be utilized at will either for forest or pasture purposes.

In the dry-farming areas of Bombay, bunding now forms an essential part of the agricultural system (8, pp. 259-261). It is generally found that bunds are most efficient when laid out on contours at intervals of 2½ to 5 feet fall. The Dry-Farming Research Station at Hagari, Madras, also recommends bunding as an erosion-control measure suitable for application by the ryots, and deep ploughing before the rainy season to retain moisture and diminish run-off (8, p. 267). Mr. N. V. Kanitkar, in a note* on erosion studies in Bombay, draws attention to the immemorial custom of constructing embankments at the lower ends of fields. Usually surface soil itself forms the material for the embankments, but in many cases large stones or boulders of the trap rock prevalent in the locality are used. It is difficult to say whether the cultivators have any real idea regarding such constructions as a measure to stop erosion. Their main aim seems to be to accumulate rainwater at the lower end of the field near the embankment, and to stop the major portion of the water and silt from entering their neighbours' fields. The position of these embankments, the actual dimensions and the presence or absence of provision for the removal of excess water vary from place to place and in many places they have no scientific background. Such works do serve to check or control erosion to some extent, but the method which aims at accumulating silt at one place at the lower end by means of a single embankment is faulty, since the accumulation of silt at the lower part is only at the expense of the higher area of the holding.

*Received from the Agricultural Expert, Imperial Council of Agricultural Research, New Delhi.

Kanitkar cites instances where, after some years, bunding has actually proved harmful. The cultivators, in their desire to accumulate silt and water, increase the depth of the soil on which water stands for a long time. This accumulation of silt changes the natural well-drained condition of the soil. Finer particles, together with dissolved material like lime and other constituents, form an impervious layer in the sub-soil. In course of time by evaporation of standing water salt concentration increases in the surface soil and causes crop failures, or the soil becomes water-logged and inaccessible for cultivation.

The hilly nature and heavy and unevenly distributed tropical monsoon rainfall of Travancore make the country very liable to erosion. "When the pressure of population on the land was lighter than it is at present, cultivation expanded only slowly. The level lands were taken up first, and then the lower reaches of the slopes. These latter were carefully laid out into terraces, protecting the edges with well rammed earth or stone bunds. The low and midland divisions thus consist of numerous little gardens, each finely terraced into one or more flats and protected with bunds which practically impound the rain water and render erosion a negligible factor.

"The problem of soil erosion assumed serious proportions only when cultivation expanded rapidly to the higher altitudes and steeper slopes. The steeper the slope, the more difficult to terrace it. A large number of high bunds will have to be built at narrow intervals, the cost of which will be prohibitive. Hence other methods of preventing erosion had to be devised. Finding it impossible to impound the water, steps began to be taken to lead the run-off water as gently down the slope as possible and thus break its force. Instead of building bunds, contour drains with only very gentle slopes were laid out and silt pits dug at short intervals.

"The land between the drains still sloped more or less steeply, and pelting rains readily washed off the loose surface soil. The next attempt therefore was to cover up all exposed surfaces with creeping or procumbent crops. In the choice of such cover crops preference was given to leguminous plants which were known to fix atmospheric nitrogen in their root nodules and thus enrich the soil in addition to preventing erosion.

"These cover crops and contour drains have however been resorted to only by the better class of rubber and tea planters. They have yet to become popular with the small holders who have not fully realized the seriousness of the losses they are suffering" (8, pp. 278-288). In view of the damage done to some estates by silt deposition from others, it is felt that a strong case could be made for the legal enforcement of erosion control in the interest of the whole community.

The desirability of some form of legal control, particularly in catchment areas which are of vital importance to the whole community, is illustrated by the conditions in the Uhl valley (Kangra district, Punjab), the 150 square mile catchment of a large hydro-electric project. Although the catchment runs up to 17,000 feet, the crux of the problem is in the

shortage of winter flow at a time when only the belt between 6,000 and 9,000 feet remains unfrozen. Most of the land between these contours is farms, made up of very ineffectively terraced fields on steep slopes, and equally steep grazing land, the whole forming an appalling picture of accelerated erosion. The position is aggravated by damage done by enormous herds of migratory goats and sheep which visit the forest immediately above the farm belt, but the problem is essentially agricultural and whatever grazing restrictions may be applied will only be a slight palliative. The only action likely to produce rapid improvement in the water régime is to acquire and afforest those blocks of cultivation which are adding most appreciably to flood peaks and the intervening periods of water shortage when the higher hills are frost-bound (3).

References (India)

1. Ayyangar, G. N. R., and Krishna Rao, P. Soil erosion. *Madras Agric. J.* **22.** 301-9. 1931.
2. Benskin, E. Afforestation in the United Provinces. Allahabad. 1922. pp. 164.
3. Gorrie, R. M. The economic importance of plant cover. *J. Indian. Bot. Soc.* **16.** 209-16. 1937.
4. ———— The foothills grazing problem in India. *Herb. Rev.* **5.** 74-8. 1937.
5. ———— Note on soil erosion in the Punjab. *Indian For.* **63.** 67-73. 1937.
6. Hamilton, A. P. F. Siwalik erosion. *Indian For.* **62.** 375-87. 1936.
7. Pusa, Agricultural Research Institute. Bull. 53. Soil erosion and surface drainage. By A. Howard. 1915. pp. 34.
8. India, Board of Agriculture and Animal Husbandry. Proceedings of the First Meeting of the Crops and Soils Wing, Delhi, 1935. Report of Committee on Soil Amelioration. 1936.
9. Jacob, W. R. Forestry in relation to climate and erosion in India. Third British Empire Forestry Conference, Australia. Papers 685-690. 1928.
10. Mann, H. H. Note on the erosion problem in the Karnatak. Agric. Dept. Hyderabad. pp. 6. 1930.
11. Smythies, E. A. Afforestation of ravine lands in the Etawah district, United Provinces. *Indian For. Rec.* **7.** 217-49. 1920.
12. Union of South Africa, Department of Agriculture and Forestry. Bull. 159. Forests in relation to climate, water conservation and erosion. 1935. pp. 62.
13. Wad, T. D., and Tambe, G. C. A note on erosion in black cotton soils. *Agric. Live Stk. India.* **3.** 238-45. 1933.

Ceylon

Ceylon was a pioneer country in recognizing the significance and consequences of contemporary erosion. In 1873, Hooker pointed out that indiscriminate tree felling was leading to denudation, but it was not until 1885 that a Forest Ordinance was passed reserving forests for protection against erosion (1). The Kelani Valley Railway Commission (1894-5) gave as a reason for extending the railway that the Kelani River was becoming unusable for transport owing to silting caused by the increased area of land in tea. In 1905, a Commission appointed to enquire into erosion in the Kelani Valley recommended the legal enforcement of regulations for opening up new land, but its recommendations were not adopted. Since then, spasmodic experiments have been made and discussions held on erosion, particularly in relation to forestry, and a great step forward was taken by the appointment in 1929 of a Government Committee "to consider and report on the question of soil erosion." In 1931 the Committee issued an extremely comprehensive Report (1) which focused attention on the increasing gravity of the situation. The incidence of a serious financial depression, however, prevented the Committee's recommendations from being adopted immediately. The Committee considered that estate agriculture was mainly responsible for erosion, and that the provision of ground cover was the primary need for its prevention, and should be universal on all estates. In particular, the Committee deprecated the strong prejudice against using ground covers on newly-opened clearings. Proper drainage, to ensure the maximum absorption rather than run-off of water, should be an important secondary consideration. Stone terraces, though useful in some cases, were held to be generally inadequate for erosion control, and conversion of old fields to the contour-platform system was usually impossible.

The present position has been summarized in a memorandum prepared for us by Mr. W. C. Lester Smith, Secretary of the Board of Agriculture. We reproduce parts of the memorandum below.

"Erosion is taking place from two causes—wind and water, but the former is almost negligible. Water erosion takes three main forms, namely:

(a) local erosion caused by heavy falls of rain in up-country areas;

(b) bank erosion caused in lower areas by large volumes of water moving rapidly along the main lines of water flow;

(c) local erosion caused by heavy falls of rain on lowland areas with a comparatively low total annual rainfall and a considerably reduced natural vegetation soil cover resulting from the long continued practice of 'chena' (shifting) cultivation and unrestricted foraging by large numbers of cattle.

"Little information is available to indicate to what extent and at what rate erosion is proceeding as a result of (b) and (c) above, so that no

comparison is at present possible between the amount of erosion taking place from these two causes. There is little doubt, however, that they are by no means negligible in the total amount of erosion taking place in Ceylon.

" Intense falls of rain are the main cause of much serious erosion. As would be expected, this is particularly so where the land is at all undulating and the natural surface vegetation cover has been removed and inadequately replaced. The rate at which this erosion is proceeding is considerable, and, though it naturally varies from place to place, it is probable that five tons per acre would not be any too high a figure at which to estimate the average annual loss of surface soil from all the dry-land cultivated areas in Ceylon as a result of this type of erosion. Holland and Joachim (2) found that under Peradeniya conditions the loss in six years under three different treatments was 101.8, 56.7 and 92.4 tons per acre respectively. All these three treatments were current estate practices. Joachim and Panditteseker̄e (3) determined that the amount of silt carried in the water of the Mahaweli Ganga (the longest river in Ceylon, 206 miles) at Peradeniya (which is not even half way between its source and its mouth, though near where it enters the low-country) varied from about 130,000 to 820,000 tons per annum. Though it is probable that much of this silt results from bank erosion, a very considerable amount of it must have its origin in the cultivated areas, mainly tea, and though the catchment area of this river between its source and Peradeniya has not been estimated, it cannot exceed half a million acres."

Mr. Lester Smith summarizes the conditions in the areas under the three major dry-land crops—tea, rubber and coconuts—as follows. Tea areas occur mainly at 1,500—6,000 feet altitude, rubber grows from 0—2,000 feet, and coconuts in the low country.

Tea

" Most tea interests recognize the fact that some endeavour has to be made to prevent soil erosion, and the majority of estates are now provided with improved types of drains designed to hold up as much water as possible. An increasing number of tea estates are adopting some form of ground cover, though it seems probable that there is still too much prejudice against the use of non-leguminous plants for this purpose. The ideal plant to grow in tea as a low ground cover has not yet been found, and efforts are being made to persuade estates to try out selective weeding instead of the more favoured system of clean weeding.

Rubber

" Generally speaking, the local rubber interests now recognize the need for preventing soil erosion by providing some form of ground cover. The majority of estates are also adopting some type of earthwork in replanted and newly cleared or planted areas. One of the greatest difficulties in old rubber areas, particularly those which have been badly eroded in the

past (probably as a result of clean weeding), is the establishment of any type of cover on eroded soils under the shade of the rubber foliage. An increasing number of estates, possibly as a partial means of overcoming this difficulty, are turning their attention to the so-called ' forestry method' of cultivation and are both permitting and encouraging the growth of a number of selected plants of all types.

Coconuts

" A ground cover (even if consisting only of grasses and other low growing weeds) is more or less general in the main coconut growing areas. While there are small areas under coconuts on land which is undulating and even occasionally hilly, the greater portion of the total area under this crop is on more or less flat land. On this account, and as most of these areas are under a natural grass or some other ground cover, the problem of soil erosion is of far less importance than it is in the case of tea and rubber, and even village agriculture generally.

" Advisory and propaganda work is carried out by the Department of Agriculture as well as by the respective crop research organizations. This is effected mainly by means of lectures to District Planters' Associations and to village agriculturists ; and also by personal contact through the visits of the departmental and research staffs to estates and the visits of agriculturists to shows and experiment stations where various methods of preventing soil erosion are under trial and demonstration. Both the tea and rubber research organizations have appointed assistants to their staffs who spend much of their time in advising small holders on the prevention of soil erosion. In addition, the Department has in hand the preparation of a series of leaflets on soil erosion, to be printed both in English and the vernacular. The control of erosion at present is left to individual enterprise which is not subsidized by the State. When, however, schemes are inaugurated for settling landless poor villagers on small holdings of Crown land in undulating or hilly areas, a small bonus is paid to each holder for the construction of drains and terraces to control erosion."

The discovery of suitable cover crops that will hold the soil but not compete for moisture and plant nutrients to the detriment of the main crop is the main objective of conservation research. The greatest difficulties appear to be encountered in finding a suitable cover for tea. Dr. T. Eden, of the Tea Research Institute, in a memorandum to the Department of Agriculture, expressed the opinion that the ideal plant would be a perennial with a penetrating, but not too vigorous root system. Weakly rooting crops suffer during droughts when they are most required, and too strongly rooting crops (e.g. *Indigofera endecaphylla*) interfere with cultivation operations. A close cover of *Oxalis* gives adequate erosion control, but is non-leguminous. Dr. Eden considered that further research on nodule bacteria and inoculation might lead to the discovery of more suitable leguminous covers than are at present known. Dr. Norris, Director of

the Tea Research Institute, suggested that a careful study of natural weeds should show which species afford good cover while being harmless to the tea plant (6). In his opinion, selective weeding could be an effective measure against erosion. The tools—the mammoty, the scraper and the wooden spear—commonly used in weeding tend to set up soil conditions highly conducive to erosion (4).

In replanted areas and clearings, the Rubber Research Laboratories at Dartonfield recommend sowing *Calopogonium mucunoides*, *Centrosema pubescens* and *Crotalaria anagyroides*. Indigenous plants, except bracken, *Imperata arundinacea* and *Mikania scandens* are allowed to grow. For mature plantations, *Pueraria phaseoloides* is a promising cover as it appears to thrive under shade.*

For coconuts, the commonest cover crops are *Calopogonium mucunoides* *Centrosema pubescens* and *Pueraria javanica* (5). These are grown primarily as green manures, and secondarily as cover crops.

The Soil Erosion Committee reported that it "was appalled by the waste of soil . . . and by the lack of appreciation of the significance of the waste on the part of many agriculturists." At first the Committee considered legislation was imperative, but finally recommended a 5—7 year period for education and propaganda before definite government action was taken. Opinion appears still to be divided with regard to the desirability of legislation, both on the score of expense and interference, but sundry ordinances have now been adopted, and others have been proposed. Mr. Lester Smith summarizes the legislation in force in March, 1937, as follows.

(1) The Land Development Ordinance No. 19 of 1935 provides for the systematic development and alienation of Crown Land in Ceylon and the appointment of a Land Commissioner.

(2) Sections 32 and 33 of the Ordinance provide that every grant of land shall contain certain conditions specified in the First Schedule to the Ordinance and may, in addition, contain any one or more conditions specified in the Second Schedule.

(3) One (the fourth) of the conditions in the Second Schedule provides that " if the Government Agent considers that any works are necessary in order to prevent surface erosion of the soil, the owner shall at his own expense carry out such works to the satisfaction of the Government Agent."

(4) Sections 155 and 156 (4) of the Land Development Ordinance No. 19 of 1935 prescribe that the Executive Committee of Agriculture and Lands may make regulations for the maintenance of reserves for the preservation of the sources and courses of streams and for the prevention of erosion of the soil.

(5) As much of the ground covered by the Land Development Ordinance is new, the Land Commissioner has laid down certain "Land

*From information received from the Director, Rubber Research Scheme.

Orders" for the guidance of the Revenue Officers in the issuing of permits and grants of land.

(6) In defining the principal objects regarding the systematic allocation of the available Crown land in a given area, Land Order No. 3 (2) states that one of the objects is to secure that various interests of the whole community are not lost sight of, one of the examples quoted being the prevention of the erosion of the soil.

(7) Land Order No. 44 lays down that " the tops, and sometimes the whole of steep forest-clad hills should be reserved to preserve the run-off and to prevent the erosion of the soil."

(8) In connection with the prevention of erosion, Land Order No. 150 states that Optional Condition No. 4 (referred to in paragraph 3 above) should be included in all permits or grants issued for steeply sloping land, and in any other case in which in the opinion of the Revenue Officer such a condition is necessary to prevent erosion. This is a condition which should normally find a place in permits or grants issued in the hilly districts, and it must not without the sanction of the Land Commissioner be omitted from any permit for high land issued in the following localities :—Central Province, Upper Uva, Province of Sabaragamuwa, Western Province, and Galle and Matara Districts.

(9) In terms of Section 156 (3) of the Land Development Ordinance the following regulations have been made in regard to the alienation of Crown land over 5,000 feet in elevation.

(1) No Crown land of an elevation of over 5,000 feet shall be alienated except in such localities as may be determined by the Executive Committee of Agriculture and Lands and approved by the Governor.

(2) No person shall be given either on permit or grant an allotment of such land exceeding 5 acres in extent.

References (Ceylon)

1. Committee on Soil Erosion. Report, 1931. Ceylon Government Press, Colombo. pp. 54.
2. Holland, T. H., and Joachim, A. W. R. A soil erosion experiment. *Trop. Agriculturist.* **80.** 199-207. 1933.
3. Joachim, A. W. R., and Panditteseker e, D. J. A soil erosion investigation. *Trop. Agriculturist.* **74.** 200-3. 1930.
4. Ceylon, Department of Agriculture. Bull. 89. Soil erosion. By W. C. Lester Smith. 1937. pp. 8.
5. Salgado, M. L. M. Questionnaire on cover crops and green manures. *Trop. Agriculturist.* **87.** 202-9. 1936.
6. Tropical Agriculturist. Report of the Proceedings of the Eighth Meeting of the Central Board of Agriculture. *Trop. Agriculturist.* **87.** 307-27. 1936.

East Indies

BRITISH MALAYA

From the standpoint of its erosion conditions, Malaya appears to be more comparable to Ceylon than to any other country. One of the principal causes has been clean cultivation on rubber plantations, a practice which shows signs of being gradually replaced by the "forestry" system of cultivation that is more common in Java and Siam (*q.v.*). Granitic soils tend to lose fertility and begin to erode particularly rapidly under clean cultivation and when once eroded the soils do not readily respond to reclamation by "forestry" methods (3). Durant (1) has described a case of catastrophic erosion on quartzite-conglomerate soil following clean cultivation, and has pointed out the extensive destruction, due to erosion from above, occurring on the lower lying rice fields.

Stockdale (4) also compares Malaya with Ceylon, stating that, with its high rainfall of between 75 and 150 in. per annum, the removal of the high tropical rain-forest which originally covered the country down to the sea coast presents excellent opportunity for damage by erosion. The agricultural development of the country has been phenomenally rapid, chiefly due to the rubber industry. The position is not so serious on Asiatic-owned estates, as clean weeding has never been adopted to the same extent as on European estates. The mining of the extensive tin deposits has also led to appreciable erosion losses.

The consequences of clean-weeding sloping estates have long been recognized and were formerly obviated or delayed by bunding or by digging silt pits on contours to catch the run-off and eroded soil (2). Terraces are rarely constructed, owing to their high cost. Cover crops are regarded as the main line of defence against erosion, much the same arguments being advanced both for and against them as in Ceylon. Perennial, rapid growing plants with creeping habits and well-developed root systems are preferred; *Calopogonium mucunoides*, *Centrosema pubescens*, *Dolichos hosei*, *Indigofera endecaphylla*, *Pueraria phaseoloides* and *Mikania scandens* are suitable both as covers or green manures. On the coastal clays, where creeping covers are unsuitable for rubber plantations, *Tephrosia candida* and *Crotalaria anagyroides* are used as green manures and soil stabilizers.

Shifting cultivation is confined to small areas in mountainous regions. Some anxiety is being felt, according to Stockdale, regarding the rapid development of pineapple cultivation as a main crop on a large scale; considerable powers have been granted to the Department of Agriculture to enforce conservation measures. Similar powers have been provided regarding the extension of tea and coffee cultivation in the Highland regions. Here the most satisfactory system of control has been found to

consist of a combination of contour silt pits, with a leguminous plant or strong-rooting grass, planted upon the bund in the form of a hedge. For this purpose *Crotalaria anagyroides*, *Clitoria cajanifolia* and Vetiver grass, *Vetiveria odorata*, have been successfully employed.

" On moderately undulating land contour silt pits, 30 feet long by 2 feet deep and 2 feet wide, with stops two feet wide between the ends of the pits, have been used with success. The distance between each row of contour pits should average half a chain. Vetiver grass has a vigorous root system which conserves the bunds. It is necessary to plant the root cuttings at not more than 4 inches apart. The grass is cut periodically and the green matter returned to the land. *Clitoria cajanifolia* may be used in a similar manner and since it is a deep-rooting legume it forms an excellent hedge plant on hill sides" (2).

Stockdale concludes that the Government and the population are alive to the dangers and adequate measures are being adopted. Owing to a different system of land tenure in the island of Penang, however, control over alienated lands is much less effective and erosion is assuming considerable proportions.

References (British Malaya)

1. Durant, C. L. Erosion. *Malay. Forester*. **5.** 109-11. 1936.
2. Grist, D. H. " An Outline of Malayan Agriculture." Kuala Lumpur. 1936.
3. Hamilton, R. A. Notes on tropical soils with special reference to Malayan soils for rubber cultivation. *J. Rubber Res. Inst.* **7.** 27-45. 1936.
4. Stockdale, F. A. Soil erosion in the Colonial Empire. *Emp. J. Exp. Agric.* **5.** 281-97. 1937.

NETHERLANDS EAST INDIES

Information on the erosion position in Java is available from correspondence between the Department for Economic Affairs in Batavia, the Forestry Research Station in Buitenzorg, and the Consul General of America in Batavia (8). In his book entitled " Addresses on geology of the Dutch East Indies," Rutten (pp. 127-9) gives a clear picture of the quantity of soil carried down annually by the rivers to the sea. He based his findings on data accumulated by the Department of Agriculture concerning the daily run-off, content of soil in suspension and of dissolved material of a number of rivers in Java, most of which information is to be found in Communication No. 5 of the Department of Agriculture, and Communication No. 1 of the General Agricultural Research Station.

Erosion is of importance especially in the Tertiary mountain and hill land situated for the most part in central and east Java (2). The principal soil types here are the very erodible tuff loam and marl formations. On the young volcanic formation and on the well-weathered laterite soils, in particular, erosion is of less importance. Sheet erosion is the commonest form which occurs. The most important factors

favouring erosion are configuration of the landscape, nature of soils and the rainfall. The rainfall, which amounts to more than 2,000 mm. annually and in the hill country may be more than 4,000 mm., is distributed over the wet west monsoon and the dry east monsoon periods, the former being the period of greatest erosion. Heavy downpours of 50 to 100 mm. per day are experienced.

As a consequence of the dense population in Java, the land is almost entirely used by the native population, with the exception of the Forest Reserve and the European farming areas. In the valleys and the plains irrigated rice cultivation is practised, but in the mountain and hill country agriculture is generally of an extensive character conducive to erosion. The improvement of this type of agriculture (in the non-irrigated land) by terracing and similar methods is very difficult to put into practice, partly because of the low stage of economic development in the native population, partly because the soil is so poor that the native does not consider it to be economical to waste more labour on it. The standard of agricultural technique on the European plantations is on the whole high ; the danger of erosion is to a large extent avoided by the construction of terraces and dams, short trenches and by the establishment of a protective plant cover.

Erosion and the removal of soil is a serious handicap in irrigation technique as the productivity of the rice fields is adversely affected if the soil which is introduced is infertile or otherwise unsatisfactory. A study has been made on the effect of irrigation waters on the rice fields (1). As erosion control by European methods (by regulating the mountain streams) does not offer a satisfactory solution to the problem in Java an effort must be made to limit erosion by the extension of Forest Reserves in certain places, and especially by the improvement of agricultural technique.

In a study of the rapidity of deforestation in the outer provinces of the Dutch Indies, Gonggrijp (9) presents a statistical survey and a general discussion of the question. He is not in agreement with the suggestion that the native use of the land is less injurious for the primeval forest and its fauna than the use of land by European planters.

The natural plant cover of Java has been destroyed on a very large scale to make way for the agricultural activities of the millions of inhabitants and for the numerous plantations of annual and more particularly perennial crop plants ; in the other islands of the Archipelago also much forest has vanished in certain localities.

According to Groeneveldt (10), within the last twenty years the destruction of forest in the outer provinces has assumed catastrophic proportions, but the authorities do not yet seem to be conscious of it. The principal cause of this destruction is unsystematic use of land for agricultural purposes. Forest fires are in the greater part of the Dutch Indies not a primary cause of the denudation of the forest area, but they follow only after other measures, without which in many cases they would

be impossible. As a consequence of the unsystematic reclamation of forest and of the later abandonment of plots of land, there is a serious risk of forest fires taking place through negligence. The desirability of immediate and strong action on the part of the Government authorities is stressed.

Especially in newly cleared areas where abundant virgin soil was at the disposal of the native population, shifting cultivation has been practised, the land being used for one or two years only without any effective measures being taken to prevent erosion. These temporary crop lands, always more or less isolated and small in proportion, were, however, deserted not so much because the fertile top layer was washed off, but rather because plant nutrients in the humus layer of the cleared forest soil disappeared so rapidly that only small harvests could be obtained. With a few exceptions, this method of land utilization does not cause any considerable denudation and the more intensive type of erosion is of no importance here.

Where, with the increasing population, the use of the land is more or less continuous, it is frequently observed that the farmers are taking effective action to hinder the injuries of erosion by the establishment of terraces, although there are certain areas in which these efforts are very incomplete. The Agricultural Education Service is carrying out propaganda for the building of terraces. The edges of the terraces are strengthened either by small stone walls or by deep rooting plants, among which the legume *Leucaena glauca* is important.

The hillside planters quickly found that it was necessary to protect the upper surface of their plantings against erosion during tropical rainfalls. Terracing with or without strengthening of the edges by planting has been adopted. Trenches or drains are frequently built in the hill land to collect the soil carried down by the stream for returning to the plantations. These trenches further promote the aeration of the soil. Denudation is very slight in the large number of very effectively terraced rice fields.

In a report on a visit to Java to study the coffee industry, Gillett (8) describes the great care which is taken in preventing soil erosion on coffee plantations. A number of figures illustrate clearly some of the methods employed.

Examples of over-stocking with animals are rather frequent, although leading to catastrophic damage in a few cases only. According to information of some old inhabitants, it appears that the erosion of the " dying land " of Cheribon, in the basin of the Tjikeroeh and Tjiloetoeng, was produced by the introduction of an excessive number of buffaloes into these poor lands at the end of the last century. This certainly lasted only for a comparatively short period, as it was quickly seen that the buffaloes could not be permitted to remain upon land which deteriorated so rapidly ; once erosion had set in, however, nothing could be done to stop it. Erosion seems to have assumed catastrophic proportions

between 1917 to 1918, when the forest land still remaining was cut and the land used for crop planting.

This outstanding case, which caused damage to lands at lower elevations owing to the deposition of enormous quantities of poor quality soil and the destruction of bridges by the river in spate, has been made the subject of intensive study by the Forest Research Station and the Irrigation Service. No plan has been evolved for stopping the further progress of erosion ; probably the population will be transferred to other areas. Reports have been published on the " dying lands " in this and other parts of Java. See Coster (3), (5), (6), and Verhoef (13).

Coster (4) describes the conditions in the native tea plantations in the Preanger Regencies, and includes photographs of neglected plantations, which show the result of failing to grow crops between the tea bushes and of frequent clean weeding. Bared roots show that more than 0.5 m. of soil has been washed away and the infertile sub-soil exposed. The tea bushes are slowly dying back and *Imperata cylindrica* and ferns are invading the land. The once fertile woodland soil is thus completely destroyed. Many hectares in the Preanger region of Java have been lost in this way.

As a whole, however, the erosion problem is not of sufficient importance to necessitate the organization of a special service for its study and control.

The various measures which are taken to regulate the irrigation water in the extensive rice fields district also have a valuable effect in limiting and preventing erosion. The protection and improvement of the forests in the basins of those rivers which supply the irrigation water serve to hinder denudation of the mountain and hill country. The amount of material carried by the rivers does not reach any very high peaks, the spates are lessened and erosion along the river courses is thereby reduced. The frequently long and much inclined conduits are provided with the necessary dams to break the force of the stream.

The Forest Research Station has dealt with the influence of hydrological work (11). Observations and measurements were carried out in specially selected land. The largest and most important area is that of Tjiwidej-Tjisaroea to the south of Bandoeng on the hillside of the old Patoea volcanic complex, where an experiment was laid down in 1930. In 1935 an experimental area of 150 hectares was arranged near Madja (Residency Cheribon), the region of clay shale and tuff sand stone, Tjisoeloeheun. In addition the Forest Research Station has the right to make observations and measurements in various areas under the jurisdiction of the Java Forest Service, where the amount and value of the eroded material are recorded. In these experiments an attempt has been made to obtain information on the relation between surface run-off and erosion on the one hand, and slope of land, nature of soil, rainfall and growth on the other hand. The soil science aspect of the work, namely, the analysis of the soil concerned, composition, erodibility and percolation have been carried out in co-operation with the Soil Science Institute of the above-

mentioned General Agricultural Research Station. The Irrigation Service, under the jurisdiction of the Department of Transport and Waterways, also plays an important part. The biological section of the Mining Service, also responsible to the above-named department, is in charge of mapping of the land.

A study which applies directly to the erosion problem in tropical countries is that made by Coster (7) on the transpiration of different types of vegetation in Java. The types of vegetation studied comprised the shrub *Eupatorium pallescens*, *Imperata cylindrica*, five Leguminosae employed as cover crops, tea and rubber plantations, bamboo forests and teak forests, and the montane rain forest. In the uplands (over 1,000 m.) it is considered that " the montane mixed forest, with a good soil cover of herbs and shrubs, gives the best possible conditions for prevention of erosion and percolation of water into the soil." In the lowlands erosion in the watershed of artificial reservoirs may probably be prevented by a vegetation of short grasses, the transpiration of which is small. In addition Coster recommends a certain amount of care in the use of quick-growing legumes as green manure crops on dry sites and during dry periods. Where there is wet soil, an admixture of heavily transpiring green manure crops may be advantageous.

References (Netherlands East Indies)

1. Berger, L. G. den, and Weber, F. W. Verslag van de water- en slibonderzoekingen van verschillende rivieren op Java. [Report on the study of the water and earth deposits of different rivers in Java.] *Meded. alg. Proefst. Landb., Batavia.* No. 1. 1919. pp. 39. 5 tables.
2. Buitenzorg, Forestry Research Station. Erosie op Java. [Erosion in Java.] Buitenzorg, 1936. [Typescript.] pp. 2.
3. Coster, C. Reisrapport No. 22 van den Opperhoutvester bij het Boschbouwproefstation. [Reports of tours. Report No. 22, by the Chief Forester at the Forest Research Station.] [Buitenzorg.] 1936. [Typescript.] pp. 20. Photographs.
4. ———— Typen van stervend land in Nederlandsch-Indië. 1. Bevolkingstheetuinen in de Preanger. [Types of dying land in the Netherlands East Indies. 1. Native tea plantations in the Preanger region.] *Tectona.* **29.** 781. 1936.
5. ———— Typen van stervend land in Nederlandsch-Indië. 2. Het areaal van de Suikerfabriek Boedoean, Besoeki. [Types of dying land in the Netherlands East Indies. 2. The area of the Boedoean Sugar Factory, Besoeki.] *Tectona.* **29.** 961-2. 1936.
6. ———— Typen van stervend land in Nederlandsch-Indië. 3. Het Tjikeroeh-gebied. [Types of dying land in the Netherlands East Indies. 3. The Tjikeroeh region.] *Tectona.* **30.** 155-7. 1937.
7. ———— De verdamping van verschillende vegetatievormen op Java. [The transpiration of different types of vegetation in Java.] *Kort. Med. Boschbouwproefstation.* No. 58. Buitenzorg, 1937. pp. 124. pls. *Tectona.* **30.** 1-125. [English summary, 103-12.] 1937.
8. Gillett, S. Report on a visit to Southern India and Java, Pt. 2. The coffee industry of Java (N.E.I.). Conclusions and recommendations. *E. Afr. Agric. J.* **2.** 149-63. 1936.

9. Gonggrijp, J. W. De snelheid van devastatie van de bosschen in de buitengewesten. [The rapidity of deforestation in the outer provinces of the Netherlands East Indies.] *Landbouwk. Tijdschr.* **49.** 410-13. 1937.
10. Groeneveldt, W. Boschvernieling in Nederlandsch-Indië, speciaal in de buitengewesten. [The destruction of forests in the Netherlands East Indies, especially in the outer provinces.] *Landbouwk. Tijdschr.* **49.** 318-36. 1937.
11. Haan, J. H. de. Boschhydrologische problemen en onderzoekingen op Java. [Hydrological problems and research in Java.] *Kort. Med. Boschbouwproefstation.* No. 39. Buitenzorg, 1933. pp. 56. *Tectona.* **26.** 932-88. [English summary, 984-5.] 1933.
12. Netherlands East Indies, Departement van Economische Zaken. [Copy of a letter on erosion in the Netherlands East Indies from the Director of the Department of Economics and the Head of the Agricultural Service to the Consul-General for America.] Batavia. 24 Nov., 1936. [Typescript.] pp. 7.
13. Verhoef, L. Typen van stervend land in den Nederlandsch Indischen Archipel. Het Paloedal (midden Celebes). [Types of dying land in the Netherlands Indian Archipelago. The Paloe Valley (Central Celebes).] *Tectona.* **30.** 220-2. 1937.

THE PHILIPPINE ISLANDS*

The Philippines are young geologically, tectonically unstable, and with many recent, and some still active volcanoes, hence with many still loose volcanic soils, and much topography with rough to steep slopes. The soils as a whole are fertile, and catastrophic erosion in places is serious. Because of the general youthfulness of the country and the continuous normal erosion of upper slopes, and the resulting aggradation of the plains, with frequent changes of elevation, or relative positions of sea and land, it is practically impossible to find well-developed laterite. Most of the rivers are short, with steep gradients, and flow rapidly into the sea, carrying with them a vast amount of material eroded from the land surface. Consequently, in spite of the dense tropical vegetation, which still covers much of the land surface, there is a great deal of erosion. The very heavy rainfall, and the very steep, deeply weathered mountain slopes cause landslides on a large scale, and these contribute a very considerable proportion of the load carried and moved by the rivers (4).

The more or less unconsolidated fragmental volcanic deposits have also been subject to serious erosion. The streams cut sometimes very deep and very precipitous gorges down into the soft tuffs, and the loose volcanic ash at times washes seriously. In one case in the Bicol region during a very heavy rain, an area of many hundreds of hectares of soil and unconsolidated volcanic ash lying almost level became saturated and, without warning, slumped out, to a depth of from 5 to 25 metres, causing much loss of life and destruction of property (3).

*This and the following section on Siam have kindly been contributed by Prof. R. L. Pendleton, soil scientist to the Siamese Department of Agriculture and Fisheries.

In some parts of the Mountain province, where there has not been enough naturally flat irrigable land for rice cultivation for local use, enormous effort has been expended by the mountain tribes in building stone walls and moving earth to make terraces for holding soil and water for " lowland " or padi rice production. Such made-land is so scarce that erosion has had to be prevented. On the other hand, near the tops of the ridges and on the upper slopes, where unirrigated crops are grown, it is customary to throw up an earth wall, with the ditch on the outside, for protection against wild pigs and other animals. Such a ditch very often concentrates enough water passing down over the slope outside of the protected field to start serious gully erosion (6).

Especially on the islands of Negros and Luzon the cultivation of sugar cane, sometimes on rather steep slopes with the furrows running up and down the slope, has been the cause of serious hill erosion, so serious that the practicable useful life of these soils cannot be much more than a decade. On some of the lower lands drainage ditches in cane fields have grown enormously (1) (2). Much of the surface of the island of Cebu, which has the densest population of any island in the archipelago, is quite rough and steeply sloping (5). From a veneer of coraline limestone which covers most of the island, the friable black clay residual surface soil has been developed. The natives of this island are maize eaters (they cannot grow padi rice on this soil) and have " caingined "* the steep slopes to grow maize, and have continued to cultivate the very steep soils until often the soil has been entirely eroded away, leaving exposed the whitish coraline rock. The Insular Bureau of Forestry demonstrated that these eroded slopes could be reforested, the soils improved and erosion markedly retarded by the use of *Leucaena glauca* and other shrubs and trees. But the pressure of population was too great, and the reforested areas have been caingined again, and erosion proceeds.

Coco palms and fruit trees are seldom maintained as clean cultures, more often they are grown as very brushy or mixed cultures of various crops together. Erosion very seldom occurs under these conditions. Abaca (*Musa textilis*) grows as forest under the shade of big forest trees.

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*A system of shifting cultivation similar to ' taungya ' in Burma, " chena " in Ceylon, etc.

References (Philippine Is.)

1. Pendleton, R. L. The drainage of cane lands in the Philippines. *Sugar News*. **6.** 621-31. 720-8. 1925.
2. ———————— A soil survey of the La Carlota area, Occidental Negros, Philippine Islands. *Soil Res*. **2.** 308-43. 1931.
3. ———————— The Bicol region. *Philipp. Agric*. **23.** 247-52. 1934.
4. ———————— Here and there in Southern, Central, and Northern Luzon. *Philipp. Agric*. **24.** 89-103. 1935.
5. ———————— Glimpses of Hinterlands in the Southern Islands: Zamboanga, Jolo and Cebu. *Philipp. Agric*. **23.** 823-32. 1935.
6. ———————— and Aquino, D. I. Soils of Bokakeng Forestry Management Project, Baguio, Mountain Province. *Philipp. Agric*. **20.** 500-10. 1932.

SIAM*

Siam is a very different country from the Philippines. Siam is tectonically stable, particularly in the central portion, and the surface topography as a whole is far nearer stability. The central plain of fertile clay rice soils is sorrounded by low undulating plains of erosion or aggradation, and less fertile soils with laterite common in the deeper horizons. There are hills and mountains, though these are as a whole not very precipitous. The higher mountains of the country are batholites of acid magmatic rock, the originally overlying deformed sedimentary material having been largely eroded away. Here and there Permo-carboniferous limestone bluffs tower above the plains or slopes. The north-eastern portion, usually known as the "Korat Plateau," is composed of mostly autochthonous fine sandy loams on Tertiary red sandstone, with a slightly undulating to nearly flat topography. In north Siam there are hills of sedimentary and granitic rocks, still quite steeply sloping in places. There are no known volcanoes, though in widely scattered localities there have been some extrusions of basic magmatic rock, now weathered to friable, red clay soils.

In the interior of central, northern and north-eastern Siam there is a longer dry season, for a considerable period each year the relative humidity is low, so that the effects of the " arid months " are accentuated by senile and consequently infertile soils, and there is often a more or less open, lower, poor forest with a considerable percentage of trees giving very hard, durable wood.

Accelerated erosion does occur in Siam, but it is hardly evident over most of the country, nor is it in general a serious problem. However, from the usually quite muddy condition of the main rivers flowing out through central and north-east Siam, we know that somewhere erosion must be going on. As Credner (1) has recently noted, the lower courses of the main rivers are at base level, and the streams are only very gradually building up the natural levees along their banks, and slowly extending their deltas out into the Gulf of Siam. Thus there is practically no erosion in the central plain, except a certain amount of channel scouring along the river banks, aggravated by the wash caused by power boats. Considerable portions of the land above the flood plain of these rivers are gently sloping or slightly undulating plains of erosion, about at equilibrium and clothed with a scant, open forest. These plains have taken the place of the sedimentary and metamorphic rocks which have been weathered and eroded away. Practically no material is eroded off from these plains, but much of what does erode from the slightly elevated portions is caught in the rice fields which occupy the lower portions of the terrain, where enough rainfall can be collected and retained to grow a crop of rice in a favourable year. That these undulating plains have been about at equilibrium for a long time is indicated by the laterite which has developed

*See footnote, p. 52.

in the soil profile and which now so generally occurs in the older soils of Siam. While usually the laterite occupies the normal position of the illuvial horizon in the profile, occasionally it has been exposed by erosion of the surface soil, and lies as hard sheets of an acre or more ; or it may be found as blocks scattered about on the surface, probably as the result of lifting by roots of trees blown over by the wind.

A similar condition, not quite so near to equilibrium, is common in the smaller plains along the eastern side of the granitic mountain ranges of Southern or Peninsular Siam. Here shore deposits and the associated lagoons have added considerably to the land area. In Phuket Island, and elsewhere in Southern Siam serious erosion, fortunately localized, and transport of silt from placer and lode tin mining have ruined rice fields and silted up rivers. Phuket bay, too, is nearly filled.

It is in the more steeply sloping mountains of northern Siam where the sedimentary rocks are frequently exposed near the surface, and where the natives, particularly certain of the hill or mountain tribes, practice caingin or " tam rai " types of agriculture, that most of the erosion from which the main rivers receive their load of mud must occur. Teak logging on the better forest soils along the lower slopes of the hills and mountains and in the narrow creek beds also contributes its share to soil disturbance and so to muddy rivers.

Often where there is caingin cultivation of the steep hills in Siam, there may be a dense growth of grass and brush in the bottoms of the narrow valleys. These growths help retain the wash from the sides of the valleys, but where the valleys are wider, the bottoms are almost certain to be occupied by lowland rice fields, or padies.

The cultivation of Hevea rubber in certain tropical countries has been notorious for the serious amount of soil erosion caused by the formerly extensively practiced rigorous clean cultivation. But while in the Philippines, most of the plantings are on a plantation scale (2) (3), in Siam, except for a very few plantations under European management, the Hevea is densely planted and practically all in small plots belonging to natives. Because of the usual abundant weed and brush undergrowth and the absence of thorough clearing of the preceding forest, the soils of Siam's rubber plantations have not eroded seriously even though most of the plantations are on low hills and sloping lands. Not only have these seemingly careless plantation methods markedly conserved the soil, but also the actual yields of rubber from such gardens are good.

The rivers of Central Siam during flood in many places flow out over their banks, and the muddy water gradually passes out through the fields of deep-water rice. In this region, since the country is almost level for great distances, for many kilometres there are practically no dikes to restrain the water on the land, and the whole plain is like one large rice field, with the water between 1 and 2 metres deep. Before the water rises special varieties of deep-water rice are sown broadcast in this plain. As the water very slowly flows through the growing rice across these fields,

much of the material in suspension settles out, so that when the water reaches the next lower canal or distributary of the river, it comes out into the channel nearly clear and quite dark coloured, having lost much silt and clay and taken into solution some organic matter. Thus the level of the plain is very gradually being raised. The colouring matter in the water and the remaining suspended matter, as well as the bottom load of the rivers, are carried on to the gulf of Siam to increase the delta deposits, held in place by the mangroves, nipa palms and other coastal swamp vegetation. Along the banks of the rivers the dense growth of fruit trees and annual crops, as well as *Sèsbania*, and aquatic plants help to protect and hold the river bank soil during floods.

References (Siam)

1. Credner, W. Siam. Munich, pp. 422. 1935.
2. Pendleton, R. L. Rubber forestry. *Sugar News.* **16.** 7-15. 1935.
3. ———————— Glimpses of Hinterlands in the Southern Islands: Zamboanga, Jolo and Cebu. *Philipp. Agric.* **23.** 823-32. 1935.

China

Discussing erosion in China, Lowdermilk (3) divides the country into three broad physiographic-climatic regions :—(1) South China, including the basins of the West and Min Rivers ; (2) Central China, including the Yangtze basin ; (3) North China, including the Hwai and Yellow (Hwang-Ho) River basins and their densely populated delta plains, containing over 100 million people. South China is mountainous, with a mainly summer monsoon rainfall of 60-80 inches ; the high rainfall and temperature cause rapid revegetation on abandoned lands thereby checking the erosion which has followed cultivation. The general soil type is given by Thorp (4) as podzolized red and yellow earths. Central China is also mountainous, with a summer rainfall of about 40 inches, and a less luxuriant vegetation (originally deciduous forest) than South China. Thorp (4) describes the soils as purple, grey or brown, with alluvial paddy soils in the valleys. North China contains the great delta plain of the Hwai and Yellow Rivers, with a loessial mountainous hinterland. The torrential summer rainfall varies from 10 to 40 inches. The natural vegetation is coniferous and deciduous forest in the mountains, short grass and xerophytic shrub on the hills and lower slopes and deciduous forest and grasses in the valleys. This is the principal chestnut-coloured loess-soil region of China, and the most seriously eroded. The Chinese loess is said to be the most erodible soil material in the world. Once erosion has started, it proceeds with great rapidity, and processes of natural revegetation are too slow to keep pace with it. Nevertheless, if erosion can be checked, new soil forms very rapidly from the loess parent material. The gigantic gullies formed by the torrential streams continually undermining the gully walls present some of the most striking pictures known of the power of erosion. The great blocks of loess broken off by the streams are rapidly disintegrated, loading the rivers with silt and causing catastrophic floods. Like the Mississippi and Po, the Yellow River is now largely a "raised" river, flowing for long stretches above the surrounding level.

Thorp, in his book " Geography of the Soils of China " (5) from which most of the following material is taken, states that " the farmers of China . . . have been conscious of the soil erosion problem for thousands of years and they have probably done more erosion control work than any other people in the entire world." In South and Central China, however, the work has been mainly incidental to rice culture. Terraces were built solely to hold back water for the rice fields but have at the same time accomplished very effective erosion control ; upland crops are usually planted in rows up and down slopes, the soil erodes badly and the fields are often abandoned after two or three years. In the north-west loess region, a vast terrace system has gradually developed as an erosion-control measure,

but without adequate safeguards for its efficiency or permanence. When the land was first cultivated, it was found necessary to build small earth barriers to hold the soil washed down from above, and each year as more soil came down, the barriers had to be raised and lengthened until now, after centuries, a complete terrace system has come into existence. The terraces themselves are actively eroding, and no proper provision is made for dealing with the surface water which runs off in drainage courses that later develop into gullies. Terraces may have saved the loess region from total destruction, but they have not stopped erosion. Strip-cropping, contour ploughing and other recognized control measures are practically unknown, and owing to the rectangular shape of individual properties and the conservativeness of the people, would be very difficult to introduce. Thorp believes that a radical change from arable farming to animal husbandry offers the most hopeful means of saving the natural grassland loess soils of North-west China, but he recognizes that this would involve a revolution in mode of living which the people would not readily accept. Short of some such revolution, however, the alternative seems to be gradual depopulation of the uplands. From a study of the conditions in the protected Buddhist temple forests Lowdermilk (3) concluded that depopulation of North-east China would be followed within a comparatively short time by reforestation. These studies also showed that most of the erosion now visible is " accelerated " and not " geological," as some authorities have believed.

Eliassen (2) states that the Yellow River transports about 2,500,000,000 tons of soil, sufficient to raise an area 400 square miles in extent five feet, every year. This quantity is more that the total carried away by all the rivers in the United States. Some of the material is deposited as fertile soil, but the gain of soil by deposition is insignificant compared with the losses from floods, famine and desolation produced in the densely populated plains by erosion. Control of silt deposition is impossible for social reasons, and " thousands of years of river regulation practice have also proven that to keep the flow to a channel is not possible for any length of time." Erosion control on the eroding sites is the first indispensable step to be taken towards curbing the destructive power of the Yellow River, and one of the greatest difficulties will be to overcome the farmers' inherent fatalism and make them nationally " erosion-minded." Eliassen is optimistic about the prospects of gully reclamation from the engineering standpoint, and believes that 70-80 per cent of the gullies in the north-west loess should yield to treatment, although the best result that can be hoped for is to save what remains of the soil. Large-scale reforestation is precluded by the population density, but timber is necessary both for constructional work and for fuel, requirements of the latter being at present satisfied at the expense of the vegetation that clothes and protects the gullies. Eliassen considers that great benefits should result from improving the present extensive but unscientifically constructed terrace system, and that it should be possible to control the worst features of the Yellow River floods by

means of detention basins (1). This would be by far the largest undertaking of its kind ever attempted, but by reason of the characteristic shortness of the Yellow River flood periods (the largest flood wave within living memory, in August 1933, occupied less than six days), it should be feasible provided the silt problem can be solved at its source.

In many parts of Central and South China whole hillsides have been completely eroded except for the rice fields which have been saved by terracing. A system of shifting cultivation has evolved in the regions where revegetation occurs quickly (3). The land is cultivated for from 3 to 15 years until it is exhausted, and then left for 20 to 50 or more years until the vegetation has formed new soil. This system has resulted in cultivation extending up to the mountain summits, although the cultivation limit is periodically lowered by famines. In less luxuriant regions, erosion goes on unchecked, particularly on grazing lands, where whole districts have been rendered almost barren. Reforestation will be necessary to reclaim these lands, but much of them is too far gone to give natural forest reproduction. The farmers, moreover, commonly burn all forest and bush land each year to destroy hiding places of wild beasts or so that the ashes may be washed down to fertilize the paddy fields in the valleys.

Sheet erosion has been particularly severe on the red and yellow soils of South China. It is believed that these soils were formerly covered by a yellowish or grey-brown surface horizon, well adapted for forest growth, but now both the original surface and underlying horizons have largely disappeared, exposing the heavy granular subsoils to gully erosion. The soils are highly leached and impoverished, and have been washed into the valleys, covering huge areas of highly productive land. On the other hand, erosion of the more fertile brown and purple soils of South China has added to the productivity of the valleys in which the soils have been deposited, although some valley areas have already been covered by the sand, gravel and rocks brought down from the uplands in advanced stages of erosion. The wealth and self-sufficiency that the Szechuan Basin maintained through many stormy times are probably attributable to the fertility of the valley soils constantly renewed by erosion from above, and to the rapidity with which the eroded uplands soils were re-formed. Climatic considerations alone would lead one to expect highly leached rather than the fertile young soils actually found on the hills and in the valleys of the Basin.

Thorp describes a peculiar form of erosion observed on the thin grassland soils of the Tibetan plateau region of Ts'inghai. "A small rodent burrows in the soil and easts the grass and plants from the surface. The burrows are sometimes caved in by grazing animals or torn open by bears who feed upon the rodents. The holes thus formed become filled with snow and ice and, by the process of freezing and thawing, become enlarged, and the sod is more or less torn apart. Running water and wind remove the granular subsoil and eventually the grass vegetation is entirely destroyed and the soil removed in great sheets. This is the source of some

of the richest alluvial soils of the Chengtu Plain of Szechuan and, to a much less extent, of the soils of the Yangtze and Yellow River deltas. Tibetan pasture lands suffer severely while the farmers of alluvial lands of China reap the benefits."

Both vertical-walled and V-shaped gullies, as well as intermediate forms, abound in China, attaining their greatest development on the loess, where they occur up to 300 feet and more in depth. Vertical-walled gullies are associated chiefly with calcareous soils in semi-arid regions (e.g. the north-western loess), V-shaped gullies with non-calcareous soils in humid regions (e.g. the leached loess of the Yangtze Valley). Composite forms frequently occur where gullies have eaten through the loess into the clay subsoil. The loess, although very porous, does not absorb water rapidly, and gullies tend to form in paths, roads, drains or any slight depression where run-off collects. Undermining accelerates the process and the silt-laden streams acquire an ever-increasing erosive force. Gullies also start by "sink-hole" erosion. During the dry weather deep cracks appear in the loess, particularly near gullies and gorges where subsoil waters have been drained away. During the wet weather, water trickling down the cracks forms a system of underground streams running over an impermeable stratum towards the nearest gully. In this way a subterranean cave is formed and enlarged by periodical washing-away of the roof and sides until finally the surface falls in, producing a sink hole. As the sink holes grow larger, or coalesce, they are converted into gullies. Similarly, sink holes often develop on level terraces where water can collect, and the farmer has to choose between a level terrace liable to sink-hole erosion or a sloping terrace liable to sheet erosion. Owing to the extreme erodibility of the loess, Thorp does not consider that damming the large gullies is a practical proposition, as it would be impossible to secure sufficiently firm foundations for the dams.

V-gullies attain their greatest development in the central and southern red and yellow earths. They are usually wider than they are deep. Except in extreme cases, damming should be quite feasible, at least to prevent further erosion and produce conditions suitable for reforestation, which appears to be indispensable for lasting soil conservation. Permanent agricultural land can be reclaimed by terracing, strip cropping, listing, etc. and Thorp considers that large-scale sowings of sunn hemp, *ipil-ipil* and other legumes to act as soil binders and nitrifiers might be very beneficial. The principal crop in South and Central China, however, is paddy rice, and the principal problem in soil conservation is the control of irrigation and flood waters from the watersheds. An extension of rice culture, and consequently terracing, would itself be beneficial, especially if combined with the establishment of irrigation works on gentle slopes and reforestation on the hills.

Wind erosion which in the past formed the loess from the desert regions and river flood plains is still active in North China, but is not very destructive. Most of the cultivated loess soils are affected in winter and

spring, but what is lost from one area is gained by deposition in another. The flood-plain soils are blown onto the hills, increasing their fertility, while new accessions of river silt are periodically deposited in the flood plain. Cultivation is extending on the sandy regions bordering Inner Mongolia, producing a new source of dust and a gradual encroachment of the desert towards the south-east.

In connexion with control measures Lowdermilk emphasizes the difficulties encountered from the traditional *laissez faire* policy of past Chinese governments in all matters of conservation, and the impotence of the small landowner to check erosion single-handed. Thorp likewise sees in government inaction and the Chinese farmer's individualism the main obstacles to securing adequate erosion control. The maximum amount of land that could be made available for agriculture is scarely sufficient to support the enormous Chinese population except in good years ; in bad years, flood and famine still wreak a terrible vengeance on the people. The centre of Chinese civilization has shifted from its origin in the semi-arid north to the more humid centre and south where land reclamation, both from the engineering and agricultural points of view, is a simpler problem than on the northern loess. Erosion has progressed so far in many districts that now reclamation is a more pressing problem than erosion control ; the land needs the surgeon's before the physician's skill. But nothing effective is likely to be done until the problem can be tackled as a whole, and on a national scale, and there appears to be little chance in the immediate future of the necessary co-ordination being obtained between all the public and private interests involved.

References (China)

1. Eliassen, S. Possibility of Yellow River flood control by means of detention basins. *J. Ass. Chin. Amer. Engrs.* **17.** 211-30. 1936.
2. ———— Soil erosion and river regulation with special reference to the Yellow River. *J. Ass. Chin. Amer. Engrs.* **17.** 22-38. 1936.
3. Lowdermilk, W. C. Erosion in the Orient as related to soil conservation in America. *J. Amer. Soc. Agron.* **21.** 404-14. 1929.
4. Thorp, J. Generalized soil map of China. *Nat. Geol. Survey of China.* Nanking. 1936.
5. ———— Geography of the soils of China. *Nat. Geol. Survey of China.* Nanking, 1936. pp. 552.

Japan*

Japan offers an example of a country with highly erodible soils and topography and torrential rainfall where erosion is effectively held in check by methods adopted regardless of cost and from a realization that the alternative to their adoption would be almost immediate national disaster. The danger from erosion lies not so much in the actual loss of soil from the steep mountain slopes as in the deposition of debris on the paddy fields. The Agricultural Department has spent up to ten times the value of eroding land to control erosion; much of the outlay, however, must be regarded as having been expended in saving the valuable valley lands from deposition from above. Thus in 1925, the Tokyo Forestry Board spent 453 yen (£45) per acre in soil conservation on a forest area valued at about 40 yen per acre; the work, however, indirectly saved rice fields valued at 240 to 300 yen per acre. Such high costs in controlling erosion necessitate the greatest vigilance in preventing its commencement, for the expense of restoration increases as the square of the extent of erosion. For many years erosion-control estimates have formed an important item in the national budget.

The soils are derived mainly from coarse-grained granites and volcanic lavas and ashes and are very easily eroded. Typical topography consists of steeply sloping, narrow valleys, the sides of which are covered by dense forest vegetation. Some of the slopes have been terraced for rice culture, but the bulk of this important crop is grown in the alluvial plains. Rainfall varies between 40 to 80 inches with downpours of as much as 12 inches in 12 hours. Wherever the vegetation cover is broken on the slopes immediate disaster is threatened until the vegetation is restored and suitable engineering works have been carried out. The dangers from erosion have been recognized in Japan for centuries, and foresters and engineers have developed an exemplary technique in obviating them. It is now a definite part of national policy to maintain watersheds under forest as the most economical and effective method of controlling flood waters and ensuring the essential food production in the valleys.

As early as 1683, reforestation on the mountains was being undertaken as a flood-control measure, but during some following periods extensive and harmful forest destruction took place. In 1781, Johann Dorehk, a Dutch engineer, introduced check dams as a means of reducing the transporting power of flood waters in the valleys, following these up with revegetation schemes for fixing the soil on the slopes. Dorehk's work has survived to the present day, and has formed the basis from which later developments in erosion control have been evolved. Systematic works

*The material in this section is derived from Lowdermilk (2).

of torrent regulation were begun about sixty years ago after a period of destructive deforestation had caused a series of disastrous floods. In 1897 a Forestry Act was passed which made torrent regulations compulsory throughout the Empire. Article 14 of the Act provides for the setting aside of protection forests for the following purposes :—

(1) to prevent denudation of the soil ;
(2) to prevent sand shifting ;
(3) to provide protection against the devastation of floods, winds and tides ;
(4) to prevent avalanches and rolling stones ;
(5) to ensure a constant source of water supply ;
(6) to afford shelters for fish ;
(7) to afford landmarks for navigation ;
(8) to improve public health and sanitation ;
(9) to maintain the scenic beauty of temples, shrines, noted places and historic sites.

In 1927, nearly 2,000,000 hectares, or 8.5 per cent of the total forest area, were included in protection forests, practically all of which were serving purposes of erosion control. If necessary, control measures are enforced on private lands, the State or local authorities undertaking five-sixths of the cost.

Erosion control is based on two principles—firstly the establishment of a base level of erosion for the drainage channel, and secondly, the artificial revegetation of the eroding surfaces when such measures are considered necessary. " Erosion control . . . . . takes on the nature of a great game of chess. The forest engineer, after studying and mapping his eroding valley, locates and builds one or more check dams. This is his move. He then waits to see what the responses of the natural forces are. The check dam establishes a fixed base level of erosion for the thalweg above it. The slipping and sloughing side slopes may after two to five years come to an angle of repose, whereon vegetation will establish itself naturally. More likely this desired result will not come so quickly. The response of the natural forces in their turn determines the forest engineer's next move, which may be another dam or two, or an increase of the height of the former dam, or the construction of side retaining walls. After another pause for observations, the next move is made, and so on until erosion is checkmated. The game takes on a lively interest. The operation of natural forces of sedimentation, plant succession and revegetation must be guided and used to best advantage to keep the costs of this expensive work down to the minimum and to practical proportions.

" The construction of check dams, or side walls, and of channel works has for its chief purpose the establishment of a base level of cutting or erosion by the stream. This stops the undercutting of slopes by the current of torrential waters. In some instances little more is needed, for the slope material comes to its angle of repose and vegetation naturally

takes possession and produces the desired protective mantles. In other cases measures are necessary to fix the soil on slopes. No attempt is made to fix slopes at a steeper angle than slopes of the same material are held by the natural vegetation in the vicinity. No more is attempted than nature has already done in the region. These works of slope fixation vary in method and application. They are terracing and sod wall terraces, wattle-work networks, adapted and suited to the situation by the forest engineer in charge.

"A distinctive feature of the Japanese technique is the artificial production of a terrace of soil on steep slopes. The slope is graded down, for this purpose, to the tenable gradient under natural conditions. Small horizontal shelves or terraces are cut in the slope, usually on 5-foot contours. Slabs of grass sod are carried to the area and are placed on end (Tsuminae-Ko), or flat and layer on layer (Tsunishiba-Ko) on this terrace. Behind the sod barriers dirt is pulled down from the slope above and tamped in place to a depth of 10 to 15 inches and width of 12 to 24 inches. In this shelf of soil seeds of the hardy Japanese alder (*Alnus firma* varieties) are sown. Pine plants (*Pinus densiflora*) are also planted. Fertilizers are sometimes applied to stimulate growth and a quick restoration of a cover. Gullies of a 'bad land' type are graded down to the slope at which they may be held under a cover of vegetation and treated in the same way."

Detwiler (1) considers that an important feature of Japan's policy is that the use of erosion-control plants is confined to a few species that have been found outstandingly successful in quickly preventing soil wash. The two most commonly used are the Japanese alder and false acacia. Control has reached a stage where serious erosion only occurs on steep, non-agricultural land which has now been reserved for forests.

In Korea, the area affected by erosion is too large and the damage already inflicted on the alluvial valleys too great to justify the costly control measures taken in Japan itself. At Seoul Forest Experiment Station, however, a beginning has been made in using hardy shrubs as a temporary vegetation cover and to act as check dams, and in sowing inoculated *Lespedeza* and other legumes in contour furrows, thereby cutting the cost to 10—20 per cent of that in Japan.

References (Japan)

1. Detwiler, B. S. Fifty years' experience gives Japan simple, effective program. *Soil Conservation*. **3.** 9-10. 1937.
2. Lowdermilk, W. C. Erosion control in Japan. *Oriental Engineer*. March, 1927.

French Overseas Possessions

Consigny (3 and 4) predicts consequences "terrible beyond the most pessimistic expectations," due to the practices of indiscriminate or careless firing of bush, savanna and forests in the French overseas possessions. The native practice of burning old vegetation in natural grasslands or savannas shortly before the rainy season in order to make room for the young growth results in increasing sterility of the soil and elimination of all but a few fire-resistant plant species. A vicious circle is formed, as the more one burns, the more does the vegetation deteriorate and the more is it necessary to burn.

Preventive and remedial measures are suggested as follows: (1) propaganda and demonstrations; (2) reorganization of the Forest Services; (3) inducement of the natives who are cultivating forest and mountain clearings to confine all burning to their own clearings (this may be ensured by leaving a 100 m. belt of incombustible forest around the clearing) and possibly to follow a certain rotation in moving from clearing to clearing; (4) inducement of native graziers to leave definite areas unburned, the superior quality of which would probably convince them of its advantages; (5) the holding of villages responsible for fires due to negligence within the territory under their supervision; (6) formation of cleared tracks from village to village, with definite camping sites, to avoid danger of fire from torch droppings or camp fires; (7) establishment of a network of firebreaks, utilizing roads, rivers, rock ridges, dense forests and clearings kept clean or planted with incombustible material; (8) the reforestation of denuded areas with incombustible timber.

The conditions in Madagascar are described by Swingle (6). Little now remains of the dense forest covering the island except a strip of mountainous rain-forest 50 miles wide, along the east coast. On the broad central plateau, with its continental climate of definite seasons of rainfall and comparative drought, the primary crop is rice, cultivated in this area by the majority of the 4 million inhabitants of the island. Shifting cultivation is practised and abandoned areas do not revert to forest but to a thin covering of inflammable grasses. Thus the area is being transformed from a fertile forest soil into a sterile, erodible, brick-like laterite.

The seasonal difference between the wet and dry seasons is much accentuated in the western third of the island. Fires are prevalent, either for rice clearings or to burn off the old grass in order to stimulate new growth. This continued burning has reduced the virginal forest cover to isolated inaccessible areas and recovery is impossible owing to the climatic conditions. A few trees resist the constantly recurring grass fires, and with a few grass species, comprise an open savanna, in place of one of the richest floras in the world.

"The final stage of destruction on the plateaux is represented by a

sparsely-grassed plain, with usually two or three species of trees and with regularly-spaced termite nests visible as far as the eye can see. . . . The magnificent tropical forest of the earth's fifth largest island has almost disappeared, due chiefly to hand-set fires. Many valuable species of plants are gone completely and with the forest have gone the unique animals. And, as pointed out by the French observers, the disappearance of the forest accentuates the dangers of the air and soil, rapidly culminating in the washing away of all soil down to the rock. Thus, rapidly are disappearing the natural riches of one of the most fertile areas of the world."

In recent years the profitability of growing "Cape peas" (*Vigna* sp ?) and maize has led to an almost indiscriminate firing of ever-increasing tracts of forest, a practice which is officially encouraged, with certain reservations, in view of the increased tax-paying capacity of the natives (1).

Maclatchy (5) describes the conditions in Gabon, a mountainous region in French Equatorial Africa covered with forests and primitive savannas and possessing a very rich flora. This region is menaced by the practice of shifting cultivation adopted by the natives, and a suggestion has been made for the formation of a natural reserve in order that its flora and fauna may be preserved.

Carle and Gattefosse (2) describe the conditions in the extreme south of Morocco (Trans-Atlas), where deforestation and excessive pasturage have caused the increasing desiccation of the country, against which the inhabitants struggle in vain. Wind erosion has caused the removal of all the soil in this region, and cultivation is possible only along certain river courses and in the oases, the last stage in the struggle between man and desert. As Morocco is a Mediterranean country, in which the rainy season and the cold season coincide, the evolution is less rapid than in tropical countries, but it is certain and not less irreversible.

References (French Overseas Possessions)

1. Actes et Comptes Rendus de l'Association Colonies-Sciences. La destruction de la forêt malgache. [The destruction of the Malagasy forest.] By M. M. C. *Act. Assoc. Colon.-Sci. Paris.* **13.** 78-9. 1937.
2. Carle, G., and Gattefosse, J. Le problème général de l'Extrême-Sud Marocain. [The general problem of the extreme south of Morocco.] *Act. Assoc. Colon.-Sci. Paris.* **13.** 189-98. 1937.
3. Consigny, A. L'avenir économique de nos possessions d'Outre-Mer compromis par les feux de brousse, de savane, et de forêt. [The economic future of French overseas possessions compromised by bush, savanna and forest fires.] *Act. Assoc. Colon.-Sci. Paris.* **13.** 49-60. 1937.
4. ———— L'avenir économique de nos possessions d'Outre-Mer compromis par les feux de brousse, de savane, et de forêt. [The economic future of French overseas possessions compromised by bush, savanna and forest fires.] *Act. Assoc. Colon.-Sci. Paris.* **13.** 73-7. 1937.
5. Maclatchy, M. A. Le territoire forestier de Mimongo (Gabon). [The forest territory of Mimongo (Gabon).] *Rev. Bot. appl.* **17.** 662-4. 1937. [Quoted from *Bull. Ass. Géogr. franç.* 1937. **105.** pp. 65-71.]
6. Swingle, C. F. Forest destruction and soil erosion in Madagascar. *Soil. Conserv.* **3.** 102-4. 1937.

South Africa

Soil erosion has already transformed parts of South Africa's richest pastoral country into semi-desert. Hall (7) quotes many authorities describing the natural luxuriance of the Orange Free State veld in the latter half of the nineteenth century. In 1866, Herschel stated that the greatest obstacles to pastoral farming were the natural richness and excessive wetness of the pastures. A witness before the Senate Select Committee on erosion (1914) attested that in 1879 the Free State was covered with rich grass interspersed with reedy pools, where now only gullies are found. In no other country have the disastrous consequences of erosion followed so quickly after its commencement. Probably the battle with erosion will be fought to a finish there first, for the land must be rehabilitated and secured before the gold mines are exhausted.

No detailed erosion survey has been published, although the desirability for an erosion map has been stressed at various conferences, and an attempt to compile one was made on the basis of a questionnaire to which, however, inadequate and misleading replies were made.* A more systematic survey, based on American standards, is under consideration. In general it may be said that erosion, as an actual or probable menace, is present in every part of the Union and is predominantly a pastoral problem. Rainfall decreases from east to west. In the Eastern Highlands, tall grassveld predominates, giving place further west to short grassveld and then to the Karroo (desert shrub) and the Kalahari desert (16). Timber forests are only found on the seaward slopes of mountain ranges, usually within less than 100 miles from the coast, and seldom occupy any extensive contiguous areas. Wind erosion occurs extensively in the western parts of the Orange Free State and the Transvaal (22). The Department of Agriculture and Forestry estimates that 92,000 acres are under drift sand in the Union. It has assumed alarming dimensions in certain coastal areas. Corresponding with the climate, the soils are mainly thin, poor in humus, frequently saline, and generally unsuited for agriculture except under irrigation which itself presents a big problem, not unrelated to erosion, in connexion with the country's limited water supply (3).

The Division of Chemical Services has since 1932 been carrying out preliminary studies on the erodibility of South African soil types. Mr. E. Fischer has kindly prepared the following summary of the unpublished results so far obtained.

" In South Africa soil conditions that favour erosion are :

(a) High clay soils low in exchangeable bases.

*Communication from Mr. C. R. v.d. Merwe.

(b) High clay soils high in exchangeable bases.
(c) High silt soils (all poor structure).

" Light sandy soils which show no illuviation in the profile near the surface (2 feet or more) are not badly affected by water erosion, because rainwater is very rapidly absorbed. Where clay pans, compact impervious layers and other unsatisfactory features occur in the profile near the surface, conditions are less favourable. The surface soil is rapidly saturated by precipitation and serious washing takes place if, after saturation of the surface layer, a heavy downpour occurs. Free surface water accumulates rapidly, due to the inability of the poorly conditioned subsoil to absorb the excess water in the surface layer sufficiently rapidly.

"In profiles of high mineral clay soils, high or low in exchangeable bases, absorption rates are low, unless the soil structure is very good. Measurement of absorption rates in soils of the above types shows that the latter type with a more or less identical clay content at the same pore space is about 3 times more absorptive. Unless therefore conditions of plant growth and topography are very favourable large water losses will take place from the former type of soil. Soil losses must invariably occur but in what proportion of water to soil little is known because there are so many variables, to wit: initial moisture content, topography, vegetal cover, intensity of rainfall and the nature and amount of material brought into suspension by the mechanical action of the rain and moving water.

" Absorption tests using rainwater containing suspended material reduced the rate of absorption considerably for a given soil. A good vegetal cover not only increases the time of contact between the water and soil but also prevents material coming into suspension by the mechanical action of the falling rain, so that conditions of maximum absorption are maintained.

" High silt soils whilst fairly absorptive erode very badly and easily, especially when subsurface conditions are unfavourable. They wash very badly, due to the almost complete lack of aggregation.

" It will be seen therefore that soil conditions favouring erosion are very wide in scope, more especially if the intermediates and combinations of types (a), (b) and (c) are taken into consideration."

The great uncertainties of the South African climate and the suddenness with which the country was opened up after the discovery of gold have contributed largely to the rapid acceleration of erosion. The conditions were particularly unfavourable to the gradual adjustment of imported farming traditions to entirely different circumstances. Towards the end of the nineteenth century it was realized that serious overstocking was taking place, but public attention was not focused on the danger until the Drought Investigation Commission (21) issued its final report in 1923. Until then, the opinion had been gaining ground that the climate was becoming drier and the rains more torrential. The Drought Commission pointed out that the available meteorological data were insufficient to prove the existence of a definite recent climatic change, but that soil erosion

alone would account for the drying-up of rivers and water holes, the falling water-table, and the increasingly disastrous effects of droughts and heavy rains which had given rise to the belief in a climatic change. With reference to soil erosion, the Commission's findings were :—

(i) That soil erosion is extending rapidly over many parts of the Union.

(ii) That, besides slooting, there is a great deal of surface erosion, both by water and wind, taking place.

(iii) That the soil of the Union, irreplaceable and definitely limited in amount, is being removed in enormous quantities annually.

(iv) That a great part of this soil and valuable plant food is lost for ever, and while the remainder of the eroded material may do good in some instances, it does much harm in others.

(v) That great damage is done by the eroded material silting up reservoirs and that soil erosion causes greater irregularity in the flow of rivers, thereby increasing the cost of irrigation works and the cost of producing feeding stuffs.

(vi) That soil erosion is causing a marked decrease in the underground water supply of the Union, and thereby increases the difficulty of watering stock.

(vii) That soil erosion is caused by reduction of the vegetal cover.

(viii) That soil erosion has a cumulative character which, by virtue of the similarity between its cause and effect, always accelerates its rate of growth, in all except a few favoured portions of the Union.

(ix) That prompt action is therefore imperative.

(x) That soil erosion is caused, mainly, by deterioration of the vegetal cover, brought about by incorrect veld management, and that all efforts to improve the latter will have a beneficial result on the former.

The worst features of veld management, conducive to drought losses and erosion, are kraaling (i.e. concentrating stock at certain fixed places at night), overstocking, and indiscriminate burning. Kraaling is practised as a precaution against the depredations of jackals. It forces stock to lead an unnatural life, weakens their constitution, increases their food requirements (by excessive driving), destroys the pasture in ever-increasing radii round the kraals, and puts a greater load on the remaining vegetation. Overstocking leads to overgrazing and all its attendant evils on the vegetation and soil ; it is frequently caused by the extreme variations in climate, and the farmer's optimism in stocking his land on the basis of a good season. Fencing and windmills, which came into use as commercial replaced pioneer farming, have also contributed largely to concentrating stock above the land's natural carrying capacity (12), although it is now recognized that fences, properly used, afford a valuable means for controlling vegetation and erosion. Veld burning is a common and age-old practice, particularly on the sour veld. In many parts it has changed the natural vegetation beyond recognition or even destroyed it altogether, especially on mountain slopes. Several reasons have been given for burning (14).

(1) Burning is done usually in early winter on both sweet and sour veld for early spring grazing.

(2) Burning to obtain autumn or winter grazing on sour veld is practised when the later stages of growth become unpalatable. When practised judiciously, it may enable pasture quality to be maintained by destroying the coarse grasses, but it tends also to suppress the nutritious species.

(3) It is believed that burning is the only way to get rid of the previous season's dead, unnutritious grasses.

(4) In the Natal highveld it effectively suppresses the coarser grasses which are the first stage to a forest or bush succession.

(5) Fire is believed to destroy certain parasites.

(6) In Bechuanaland, large tracts are burnt by natives to facilitate hunting.

Burning affects erosion by removing the vegetative protection to the soil, leading to a hardening of the surface by stock trampling and sun-baking, thereby increasing run-off. Abnormal moisture losses, both surface and underground, occur through increased evaporation and intensify the general dessication of the country. The destruction of soil organic matter also predisposes the soil to erosion. Du Toit (4) considers that veld burning may be permissible on sour veld, where it seems to be the only practical means of controlling surplus growth and preventing reversion to forest, but on sweet veld it should be dispensed with altogether.

Other causes of erosion have been deforestation, particularly by natives for timber and firewood, and road and railway construction. The concentration into culverts of storm water draining from railways and roads has ruined parts of many farms which the improved transport should have benefited. The tsetse menace may necessitate more deforestation in North Bechuanaland and Zululand (3), but attempts are now being made to deal with it by fly-trapping. Much stream-bed erosion has been caused by the destruction of riverside trees.

The South African climate and relief are such that less than 15 per cent of the land area is suitable for, and less than 5 per cent under, cultivation (12). The country is, and apparently always must be, predominantly pastoral, and by far the most important problem confronting pastoralists, and perhaps the whole nation, is how to prevent sheet erosion by maintaining an adequate vegetation cover through controlled grazing. The official attitude seems to be to aim at discovering, and then if necessary enforcing the best principles of pasture management rather than to discourage indiscriminately or prohibit kraaling, veld burning, etc., which are ingrained in the South African's attitude to the land and may ultimately find a restricted place in a suitable pastoral system, which must be determined for each region according to the prevailing soils, vegetation and climate.

Leppan (13) considers that in a policy of land utilization concentrating almost entirely on properly organized animal husbandry

lies South Africa's chief hope of salvation. He traces the past policy of encouraging cereal production, assisted by export subsidies, tariffs and a magnificent elevator system, to the economic consequences of the South African war, and points out that the reverse policy of encouraging cheap grain imports would have the effect of increasing soil fertility, thereby helping to save the veld from erosion. The imported feeds would be used to relieve pressure on the pastures, and not to carry more animals, which should be fewer and of better quality. More use should be made of cultivated land in producing animal rather than human food. The meat market could be enormously extended, and the demand for maize proportionately reduced, by educating the natives and raising their standard of living. Leppan considers that the land is overstocked with men as well as with animals and that a white peasant class is undesirable in South Africa. This opinion is not universally held. Leppan recommends fostering urban activities to relieve pressure on the land, and the State purchase of derelict farms which might be rented on long leases with due safeguards against overstocking and other maltreatment. All economic and political measures, however, are useless unless they are supplementary to *controlled veld management*, which is the crux of the whole problem.

The most potent factor in veld destruction is overstocking, both on European and native land. Remedies aim at either eliminating or controlling the destructive factors and re-establishing vegetation on bare areas. The problem is being tackled both from the ecological and practical (e.g. pastoral systems) points of view.

Bayer (1) has studied the relation of vegetation to erosion in the thornveld, the area most subject to erosion in Natal. The thornveld appears to be an unstable association, developing from the invasion of grassveld by heliophilous trees under whose protection clumps of shade-bearing trees come in later on the moister areas. Several unsuccessful attempts to control erosion have been based on encouraging or planting the indigenous acacias, exotic trees usually dying from drought. It has been found, however, that even dense acacia scrub has little effect in preventing erosion, owing to the small amount of litter deposited. In moist areas near water courses a satisfactory tree growth develops, but in the drier areas it is impossible to force the succession beyond the pioneer acacia stage. The pioneer trees offer no check to run-off, but tend to suppress the grass, thereby actually causing erosion and the death of the trees and checking the development of the " clump " climax.* Under favourable conditions, grass then re-appears and regenerates the soil. This is an example of erosion occurring without human intervention; the cycle of tree growth and erosion alternating with grass growth and regeneration has apparently been going on for centuries. The human factor, however, has intensified the erosion part and eliminated the regeneration part of the cycle. The aim should be to produce conditions

*Mr. J. D. Keet, however, states that luxuriant grasses grow under thorn trees, but are often trampled out by stock seeking shelter.

similar to those in the less eroding " clump " regions, and Bews's observation of the frequent occurrence of termite mounds in the clumps suggests that these mounds, by obstructing run-off, increases the soil's water content. It should be mentioned, however, that the " harvester termite " has been shown to be largely responsible for retarding grass regeneration throughout the Transvaal and Natal thornveld. Bayer proposes a system of short trenches, imitating the termite mounds, along contours to act as centres from which colonization by grasses would begin. Once the vegetation was established, it should only be necessary to avoid fires and overgrazing in order to conserve the veld.

Rowland (17) has described how, before land was enclosed in the Potgietersrust district, natural conditions sufficed to prevent overstocking. Any tendency in that direction was soon checked by losses caused by mineral deficiencies and other diseases among both stock and wild animals. Stock numbers seldom rose above the winter carrying capacity which was limited by the drying-up of temporary summer watering places and the low feeding value of the grass veld in winter. During the summer, not only was a greater area available for grazing by reason of more watering places, but also many cattle trekked to the High Veld, leaving a much lower stock concentration than in winter. Furthermore, the seasonal palatability of the different veld types produced some amount of rotational grazing and gave the land intermittent resting periods. These natural prophylactics have been abolished by veterinary science, the curtailment of trekking and the construction of artificial watering places by dams and bore-holes. Rowland considers that detailed studies of ecological succession under modern grazing conditions combined with careful limitation of grazing is the only sure way of controlling veld deterioration and erosion. The natural flora under free grazing conditions was quite different from that which can survive under modern grazing systems. Only a careful study of plant succession under different grazing conditions can show which system is best suited for each type of locality.

Carefully conducted experiments at Pretoria (18) indicated high erosion losses and run-off accompanying cultivation of crops and veld burning. Annual hay crops were less detrimental. Among perennial planted grasses, Rhodes grass was most effective in preventing erosion and run-off. Close summer rotative grazing considerably increased run-off, but had little effect on erosion, compared with leaving the veld intact. Organic manures applied to maize reduced erosion and, even more, run-off, but the losses were still very high.

Other general ecological investigations, bearing on erosion, in progress at research stations include (19) :

(1) Experiments in connexion with the correct methods of veld management and veld reclamation for different areas and the effect on the veld of certain factors such as natural and artificial fertilizer, controlled grazing, rotational grazing, veld-burning, etc.

(2) Tests are being undertaken to demonstrate the value of artificial

pastures as a means of supplementing the veld during times of scarcity, as well as a means of resting the veld.

(3) In regard to grass-breeding, every effort is being made to breed the most suitable, nutritious and drought-resistant woolly-finger and other grasses through crossing.

(4) The most promising indigenous grasses are being tested out in order to determine their qualities as pasture or ensilage, their nutritional value, their response to fertilizer, etc.

(5) Experiments are being conducted with a view to breeding grass varieties that can be propagated on a large scale from viable seed.

Much emphasis has been laid on the need for paddocking, to replace kraaling, to secure complete control over the veld and to allow rotational grazing. The Drought Investigation Commission recommended paddocks of 100 to 1000 morgen, depending on the carrying capacity, but recognized that paddocking would require an adequate and pure water supply, which was not always obtainable. The cost of fencing is also a considerable deterrent to adopting this system, which acts more as a preventive of further damage than as a cure for past evils. Hall (7) states that many areas have gone too far to be reclaimed by grazing control, and sees in the contour furrow or ridge terrace one of South Africa's great hopes for the future. The ridge terrace is especially useful on gullied land, where it is cheaper and more efficient than damming. It not only restores and irrigates the veld, but also controls flood waters, reduces silting, prevents dams from breaking, and rejuvenates springs.

The extraordinarily successful reclamation work carried out by Mr. Howard Hobson on his farm, " Pinekloof," in the Orange Free State, is revolutionizing the treatment of gullied land. The basis of Mr. Hobson's methods may be said to be to make use of existing gullies (" dongas ") as water reservoirs by filling them with water rather than to attempt the more costly task of filling them with earth. Thereafter, excess water flows over the top of the dam as harmlessly as if the gully was not there, and at the same time the farmer secures a valuable water supply. " Till the discovery was made that a donga full of water will not extend along the course of an intermittent stream running into it, and that only a small section of the donga need be filled in this manner to enable us to re-distribute the water over the watershed at will, there was no feasible means of tackling erosion, for the cost of treating even a single valley by any other means was prodigious and inefficient.

" The scope for application of these methods in conjunction with the well-known principles of contour construction is so wide and varied that only a personal study of the works here can adequately describe them."*

What was once regarded as the " mad idea of pouring large volumes of flood water over the vertical banks of dongas of any depth at a point immediately upstream of a dam embankment " is justified by Mr. Hobson in the following words (8).

*Private communication from Mr. Hobson.

"Given a grass-covered approach to the edge of the erosion cliff, the donga or erosion can only extend by an undercutting process of the base of the cliff. When the donga is full of water there is no cliff, and as soon as there are a few feet of water in the bottom of the donga below the water-fall, the water acts as a cushion and then there is no undercutting.

"Should a little breaking back take place at first, the soil is no longer carried away, but is deposited below, thus reducing the fall.

"In course of time the banks of the donga slope off. Suitable grasses, if absent, should be planted which, as the water level is lowered in the dam, spread down these slopes and protect the inlet during the brief periods of succeeding fillings of the dam.

"When such dams are liable to become quite empty frequently, it may be necessary sometimes to pave the slope of the inlet with rough stone-work.

"The choice of the site for the embankment across the donga is all-important. This should be built whenever possible a little below the point where the diverted stream would naturally return to the donga. This is the lowest point and consequently the point where the water will soonest reach the level of the banks and flow across the donga."

Disposal of surplus water is controlled by (usually short and low) contour banks constructed so that the water may be distributed usefully over the vlei pastures, or else be returned lower down to the gully or natural drainage channel, where it is dammed by another embankment. Mr. Hobson considers that, under South African conditions, the water supplied, via dams and along the natural drainage channels, to contour systems gives the latter their greatest value. He does not approve, as a standard practice, of narrow, "staggered" openings in a series of interrupted contour banks.

"The writer has never favoured this type of construction, especially for streams diverted from the natural drainage channels, for the simple reason that if it has been necessary to construct contour banks of any appreciable dimensions at all, they will frequently be called upon to deal with large volumes of water and the principle of releasing strong streams through narrow openings on to slopes is bad.

"Why the width of opening should bear any relation at all to the length of sections of bank, I cannot see. I prefer, therefore, to reverse the ten-to-one proportion of bank to opening suggested, and on uncultivated land only use banks in contour works to convey water to desired areas, to get past danger points and across depressions, the rest being open channel.

"The advantages of distributing water by the method indicated compared to the gushing torrents discharged through narrow openings in contour banks are obvious."

To Mr. Hobson, anti-erosion works are a matter of common sense—"just a few strips of the lost soil replaced in the right spots and raised

above the level of the surrounding ground" have saved his extensive farm and made it an outstanding example to the Union. One authority described his system as a cheap and infallible one that would save South Africa.

The tremendous damage done by gullies to the land, to the rivers and to the underground water supplies naturally drew early attention to this most spectacular aspect of erosion, and it is not surprising that the Government has largely concentrated its efforts at State assistance on gully reclamation. It should be mentioned that the authorities are fully aware of the importance of tackling gully formation at its source, by controlling sheet erosion and flood waters at the watershed, but it is thought that improvement in veld management and maintenance, forest and watershed protection, etc., can at present be accelerated more by education and research than by direct financial assistance. Government action (on European land) is confined to giving various forms of assistance and encouragement to individual farmers undertaking reclamation works. There is no compulsion except with regard to limiting stock on Crown land that has been reclaimed under a Government scheme (9). Local Soil-Erosion Committees, consisting of the magistrate and two farmers appointed by the Agricultural Departments, have been formed to deal with all applications for assistance, to inspect land and to arrange for technical advice, where necessary.

The five Government schemes of assistance, available in March, 1937, are set forth in Circular No.22 of the Department of Agriculture and Forestry :—

"In view of the rapid and devastating spread of soil erosion in South Africa, it has become urgently necessary to combat this national evil, and various measures have therefore been instituted by the Government to assist landowners in combating the evil and to encourage them to erect anti-erosion works.

"Applications may be submitted for assistance under any of the schemes referred to hereunder, *but no application can be considered in respect of any works that have already been completed or have been commenced before the applicant has received the approval thereof from the Department or its representatives.*

(1) Scheme A, i.e. where the works are to be completed at the applicant's expense, a bonus of 25 per cent is paid on the valuation of approved works, if the application was made prior to 1 April, 1936, and a bonus of 33⅓ per cent on the valuation of works in respect of applications submitted after that date.

(2) Scheme B : Loans may be granted to cover the construction of approved works, as also a subsidy of 25 per cent on the final valuation thereof.

(3) Scheme C, under which the State meets seven-eighths of the wages of unemployed European labourers employed in

the construction of anti-soil erosion works and small dams approved by the Department.

(4) Scheme D provides for loans for the purchase of implements and material and for the erection of huts required in connection with Scheme C.

(5) Scheme E permits payment of a bonus of 25 per cent, on the final valuation of fencing erected for the protection (a) of trees and shrubs planted as an anti-soil erosion measure, and (b) of eroded areas."

In his Annual Report for 1936 to 1937, the Secretary for Agriculture and Forestry gives the following figures showing the extent and cost of works carried out under the three first schemes since their inception in 1933.

	Number of dams applied for and approved.	Preliminary estimated cost of dams.*	Preliminary estimated cost of anti-soil erosion works.*
		£	£
Scheme A	11,065	1,027,850	194,068
Scheme B	1,429	150,446	15,811
Scheme C	5,566	984,964	175,702
Total	18,060	£2,163,260	£385,581
Cape Province	10,300	1,270,093	265,279
Orange Free State	4,134	504,897	96,691
Transvaal	3,162	342,505	17,925
Natal	464	45,765	5,686
	18,060	£2,163,260	£385,581

*All costs under Scheme C apply to *wage* costs only.

The Secretary admits that the schemes have not entirely fulfilled their original purpose; attention has been paid to damming rather than to "anti-soil erosion works" (contour banks, gully repairs, etc.). It has been argued that the lure of a subsidy for damming, and not land reclamation, is often the main incentive for undertaking work which consequently is not executed with adequate regard to its real object. Some critics consider that Scheme C was drafted primarily to absorb unemployed and not always efficient white labour, often resulting in serious constructional failures. The Government is alive to these and other criticisms and modifies the schemes as experience in their working is acquired. The Department of Agriculture controls the major part of the anti-erosion campaign, but the Division of Forestry is very active in the drift-control campaign and in all matters affecting forestry.

Similar schemes were instituted in 1936 to assist the reclamation of wind-eroded lands. Inland wind erosion originates from much the same causes as water erosion, namely, over-cultivation, overgrazing,

veld burning, trampling by stock, etc. In the dune country, in order to escape midges and flies, stock rest on bare patches which are soon enlarged, forming centres from which drifting spreads (9). Roads worn deep into the sand and paths made by driven cattle also often start soil drifting. The cause of the extremely prevalent coastal drifting is usually destruction of the vegetation stabilizing the dunes that bar the inroad of wind-borne sea sand.

Control of coastal drifting consists in preventing pasture destruction and in fixing dunes by planting trees (e.g. wattles) along the boundaries of the dunes, erecting catchment fences, covering the sand with branches and bushes, and establishing sand-binding grasses (*Ehrharta gigantea* and *Psamma arenaria*) (5). These measures are usually temporary expedients to hold the sand until a scrub or tree vegetation is permanently established. Reclamation of large areas may take 10-20 years and demands constant care and attention, and a highly specialized technical knowledge.

Van Vuren (22) considers the maintenance of humus as essential for permanent control of inland drifting, as wind erodibility is much enhanced by the low water-holding ca acity and the pulverization of humus-poor soils. Pasture fertilization, growing fodder crops for winter use and returning all manure to the land are recommended as means for maintaining or increasing the humus. In badly exhausted soils, where fertilizers will not restore productivity, ploughing in a green manure crop or hay stubble is the best way of protecting the soil. Cultivated soils should be worked with a harrow or mould-board plough immediately after rain. Disc ploughs crumble the sod too much, and should be avoided.

On the coast of South-West Africa there is an enormous belt of drifting sand estimated to cover 8,500 square miles, extending in places 80 to 85 miles inland, the drifts reaching 700 feet in height (10). The Kinseb River has already been deflected many miles from its original course and seldom reaches the sea above ground. Apart from the extent of the area, the aridity of the climate makes reclamation impossible except by natural processes including a climatic change. Some such climatic change must have occurred in the Kalahari, where former barren sand dunes are now clothed with natural savanna forest. On the south coast of the Cape Province, the state of equilibrium reached in course of time by the sand dunes is being disturbed by an apparent change in the direction of the prevailing wind from south to south-east or south-west.

Erosion in Native Reserves

Conditions in the native Reserves are well illustrated in a communication (dated March 13, 1937) received from the Chief Magistrate of the Transkeian Territories through the Soil Bureau's Official Correspondent. The Territories cover over 16,000 square miles, of which 13,000 are native reserves. About 4,000 square miles are under cultivation, the rest being available for grazing (11). Some 1,500,000 cattle and 4,660,000 small

stock comprise the animal population of the Reserves. These numbers are considerably in excess of the maximum grazing capacity.

The Territories extend from the Drakensberg to the Indian Ocean and from the Kei River to Natal. Climate varies from highveld grassland to sub-tropical bush, and rainfall from 20 to 50 inches a year. Erosion is most severe in the 20-25 inch belt and in mountain districts, and practically non-existent on the moist, sub-tropical coastland. There is no evidence that erosion existed fifty years ago ; it has now reached an advanced gully stage practically everywhere. The communication referred to states, *inter alia* :—

" Prior to the coming of the European, the native was a nomadic hunter and pastoralist ; he produced very little from the soil. Within recent years his mode of living has completely changed. He is now primarily an agriculturalist and secondly a pastoralist. In other words he exists mainly on mealies grown by himself and regards his cattle as wealth negotiable only in times of dire need.

" He has increased considerably in numbers and the Territories can now be said to be overpopulated and overstocked, the latter condition arising out of the former.

" To-day the general appearance of the Territories presents the following picture :—

(1) Grazing grounds are largely trodden out, seeding rarely takes place and quality of grazing is seriously impaired.
(2) Every available foot of arable land is used. Lands have been badly located and frequently occur on very steep slopes.
(3) Indigenous forests and bush have largely disappeared.

" As a result of these conditions, together with the presence of numerous sledge tracks, footpaths and cattle tracks to dipping tanks (there are 639 of the latter in the Territories), the vegetation is very short and the land consequently offers little resistance to erosion from heavy rains and wind. This serious state of affairs which exists may be attributed to :—

(1) Overstocking, resulting in the deterioration of vegetation.
(2) The disappearance of the natural forests due to indiscriminate use of forest produce.

" While the number of stock per acre is far in excess of what it should be, the fact remains that the number of stock per family unit is barely sufficient for its needs if an average is taken per family.

" In 1926 the Council voted the first sum of money for reclamation purposes ; a start was made by fencing gullies and the construction of stone barriers in the beds of the gullies. These barriers were costly and it was difficult to build the ends satisfactorily into the sides of the gullies to prevent the sides being eaten away during floods, consequently it was frequently necessary to rebuild or extend them. Wire barriers were also tried, but, for the same reasons, although they could be constructed more cheaply, were not satisfactory.

"From 1932 the construction of barriers was discontinued owing to the high cost of maintenance, but the policy of fencing eroded areas and dongas was continued, and, in addition, dams were built at the head of dongas to divert most of the storm water, the sides of the dongas (where not too costly) were sloped and planted with grass and trees.

"Up to 1936, the work was directed and controlled by the Agricultural Department of the General Council. The following are the totals of work done while under the Agricultural Department's control :—

787 dams constructed.
260 barriers constructed.
330 springs fenced.
233 eroded areas fenced.
106,397 trees planted.

"The amount expended from 1926 to 1936 was £77,832."

Fencing and contouring is being energetically continued by the Engineer's Department of the General Council with satisfactory results both on gullied and sheet eroded land. The communication, however, continues :—

"The anti-erosion works which have been carried out will help, but native customs and mode of living render effective reclamation measures exceedingly difficult.

"Only the following drastic steps will solve the problem :—

1. Reduction in the number of stock, which is not a feasible proposal.
2. The purchase of additional land to alleviate the over-population.
3. A definite scheme of stock and grazing control."

The position is equally, if not more, serious in other native areas which cover some of the best watersheds and basins of the principal irrigation rivers (e.g. Vaal and Telle) (20). The natives, formerly pastoralists, are becoming agriculturists, and cultivation promises to extend rapidly over all the usable land in these watershed areas. Soil conservation works, therefore, have to take into consideration native customs and limitations, and have to be planned to fulfil three functions, viz. :—(1) to prevent erosion, (2) to prevent uncontrolled irrigation with storm water, and (3) to contour the land for agriculture. In the opinion of the Director of Native Agriculture (20), contouring, and ultimately terracing, is the only means of securing the soil against erosion.

Anti-erosion work was started in other native reserves towards the end of 1933, and at the end of April, 1934, in one district (Herschel) alone, 62 miles of contour banks and 132 earth dams had been completed. Protection works consist in building diversion walls and training banks near the watersheds, and distributing the flow as evenly as possible by means of interrupted contour banks which are constructed to conform to the nature of the relief and soil and with a view to their ultimate utilization in a terrace system. The stabilization of the banks by suitable grasses

and other plants should be ensured as soon as possible, and when accomplished, the gaps between banks can often be closed so that the water passes in a thin film over their entire length. Where the waters have been properly controlled from the top of the catchment basin, embankments may sometimes be continued across gullies and produce very satisfactory siltation. Badly sheet-eroded lands are reclaimed by fencing and prohibiting grazing. The total area treated for erosion in the native reserves (excluding the Transkei) at the end of 1937 was approximately 30,000 morgen, at a cost of about £84,000.

Labourers engaged on reclamation work receive sixpence a day plus 3-5 pounds of mealies. When the reclamation works have been completed, suitable grasses and trees are established, and a part of the area (usually not more than a third of the total) is fenced off and reserved for winter grazing.

As is happening throughout the Union, the Department of Native Affairs is becoming increasingly alive to the fact that grazing control, veld management and overstocking should receive prior consideration to reclamation works, and more attention is now being given to the former. Slow but sure progress is being made in educating the native to think in terms of cattle quality rather than quantity. Funds have been provided for improving village amenities, orchards and trees for future fuel requirements have been planted, and dams for watering have been provided, fitting into the general anti-erosion scheme. These have greatly stimulated popular support for the measures taken (6). On the other hand, attempts to engender price in quality stock by holding annual shows, and stock sales to induce natives to cull their herds, have been generally unsuccessful (15).

A matter of considerable moment to the Union is the political future of the three native Protectorates, especially Basutoland, which contains the dominant watershed in South Africa. It is felt that a nation-wide plan to control erosion and soil moisture would be incomplete and might be ineffective without unified co-ordination with the Protectorates (2). In the Union itself, the Government has for some years followed the policy of acquiring watershed areas for preserving the natural flora and fauna in national reserves, and the people look to the British Government to complement that policy by adopting similar measures, where necessary, in the Protectorates.

Basutoland contains the greater part of the Orange and Caledon catchment areas, and is normally a well-watered country. Its stormy history of intermittent warfare during the last century probably prevented excessive erosion, but at the present time " erosion in its many aspects is the most immediately pressing of the many great problems which confront the Administration " (6). In the level or undulating lowlands, poplation pressure has brought nearly all available land under the plough, intensifying overstocking on the remaining pasture. Cultivated fields are relatively free from serious gully erosion, but it is estimated that

10 per cent of the arable area is badly affected and the whole fabric of land is threatened by the rapid spread of the gullies. In the mountain highlands, steep slopes are being brought under cultivation as the population increases, but overgrazing is not serious below altitudes of about 7,500 feet, above which overstocking by animals driven from the lower levels is prevalent. Vast former grassland areas have been invaded by the " bitter Karroo " (*Chrysocoma*), an inedible plant, but useful as a soil binder, and by a ragweed poisonous to horses.

The lowland soils are mainly sands of the Karroo system, the mountains contain doleritic masses which produce very fertile soils in the mountain valleys. The erosion problem is much the same as elsewhere in South Africa. A major difficulty is to overcome the Basuto's strong prejudices against any kind of fencing, and it is possible that since erosion control will be for the benefit of the neighbouring Union States at least as much as of Basutoland itself, the native chiefs may react against having to display more than the necessary altruism. The effective co-operation of a large number of small stock owners will have to be secured to ensure the success of any comprehensive reclamation scheme. Such a scheme, based on a careful ecological survey*, was suggested in 1935 by the Dominion Secretary's Commission (6), and in 1936 a loan not exceeding £160,233 from the Colonial Development Fund was granted to Basutoland for a 10 years' campaign along the lines suggested. In the Annual Report for 1936 of the Department of Agriculture, it is stated that over 100,000 yards of contour banks and 20 dams have been constructed, and that the natives are beginning to appreciate the work and are asking for contour banks to be erected in their fields.

*The manuscript of a report on " An ecological survey of the mountain area of Basutoland," by R. R. Staples and W. K. Hudson, has been received. The three chief sections of the report deal with a general description of the mountain area, its utilization and the problems arising through its use. Deterioration of pastures has led to erosion, for which the only remedy appears to be the adoption of suitable systems of deferred grazing and the limiting of stock according to the carrying capacity of the pastures. Two simple grazing systems are suggested, one for the cattle post country and the other for the village areas. Provided the present numbers of cattle are not exceeded, and are properly distributed, no overstocking need occur. Wholesale overstocking may become general again and action is necessary to avoid this. These measures, combined with an investigational programme to provide guidance for future protective measures on these valuable pastures and watershed areas, are considered to be the most essential.

References (South Africa)

1. Bayer, A. W. The relationship of vegetation to soil erosion in the Natal thornveld. *S. Afr. J. Sci.* **30.** 280-7. 1933.
2. *Bloemfontein Friend.* Feb. 2. 1937.
3. Du Toit, A. L. Some considerations upon agriculture and mining in South Africa. *S. Afr. J. Sci.* **31.** 1-24. 1934.
4. Du Toit, E. Further aspects of the soil erosion problem. *Fmg. S. Afr.* **9.** 295-6. 1934.
5. Du Toit, R. Protecting the pasture against wind-blown sea-sand. *Fmg. S. Afr.* **9.** 403-4. 1934.
6. London, H.M. Government. Cmd. 4907. Financial and economic position of Basutoland. London, 1935. pp. viii+225.
7. Hall, T. D. South African pastures : retrospective and prospective. *S. Afr. J. Sci.* **31.** 59-97. 1934.
8. Hobson, H. Are engineers the men for erosion control? *Farmer's Weekly.* **49.** 1004-5, 1025-26. 1935.
9. Keet, J. D. Soil erosion and allied problems in South Africa. *Brit. Emp. For. Conf. Union S. Africa, Pretoria,* pp. 18. 1935.
10. ———— Report on drift sands in South Africa. *S. Africa Dept. Agric. For. Bull.* 172, pp. 35. 1936.
11. King, N. L. The menace of soil erosion in the Transkei. *Territorial News,* Jan. 14, 1937.
12. Leppan, H. D. The interdependence of animals, crops and pastures with special reference to South African farming. *Univ. Pretoria Ser.* 1, No. 37, pp. 21. 1936.
13. ———— The organization of agriculture with applications to South Africa. *Cent. News Agency, Johannesburg,* pp. iv, 83. 1936.
14. Liebenberg, L. C. C. Veld burning. How it affects the farmer as well as the country. *Fmg. S. Afr.* **9.** 213-5. 1934.
15. *Natal Mercury.* July 2, 1937.
16. Pole Evans, I. B. Vegetation map of South Africa. 1935.
17. Rowland, J. W. Notes on the study of plant succession in relation to grazing. *S. Afr. J. Sci.* **30.** 307-16. 1933.
18. Thompson, W. R. Rainfall, soil erosion and run-off in South Africa. *Univ. Pretoria Ser.* 1, No. 29, pp. 31. 1935.
19. Union of South Africa. Department of Agriculture and Forestry. Annual Report for the year ended 31 August, 1936. *Fmg. S. Afr.* **11.** 498-502. 1936.
20. ———— Department of Native Affairs. Combating soil erosion in native reserves of the Union (excluding the Transkei). pp. 13. 1935.
21. ———— Drought Investigation Commission. Final Report 1923. Cape Town, pp. 222.
22. Van Vuren, J. P. J. The problem of wind-eroded lands. *Fmg. S. Afr.* **12.** 108-9 and 125. 1937.

Rhodesia

SOUTHERN RHODESIA*

Climatically, Southern Rhodesia is similar to the north-eastern portion of South Africa, the rainfall, which occurs mainly during the summer months, varying from under 15 inches in the low-lying country bordering the Limpopo River to over 50 inches along the escarpment on the eastern border. The Colony has been developed more recently than the Union, but the chief stimulus to its development—mining—has been the same. A large proportion of the soils is granitic in origin, and not very suitable for extensive agriculture without fertilizers. Tobacco-growing, however, is increasing in the granite areas with a normal rainfall of over 25 inches. The heavy, black vlei soil seems to be particularly dangerous to cultivate when drained on a slope (1), and expert advice is now usually obtained before any vlei is drained. The most suitable soils for agriculture, producing practically all the maize grown, are derived from basement schists. Sheet erosion is severe on the oldest and best cultivated soils, often located on slopes, in the northern districts of Mashonaland, where many areas have also been destroyed by "mining" the soils (3). Soil conservation is now being accelerated as quickly as possible, and at the end of 1936 about 11 per cent of the arable land had been protected by ridge terracing. The present rate of progress is about 3 per cent of the total per annum (4). As the average soil loss in Mashonaland is estimated at $\frac{1}{4}$ inch a year, an acceleration of soil-conservation measures is clearly desirable. Considerable damage has been done by large landowners accepting native tenants without adequate supervision of the use the tenants make of the land (4).

Gully erosion is extensive on range land and in native reserves, principally in Matabeleland. On native lands, the "lobolo" system of purchasing wives with cattle is largely responsible for the excessive overstocking which is the main cause of erosion. In swampy areas and in districts with heavy rainfall, the native practice is to plant crops on ridges formed with soil excavated from ditches running down steep slopes. Ploughing up and down slopes was formerly almost universal in native areas.

Veld burning, in order to hunt mice and rodents for food, and clearing bush land and abandoning it after a few years' cultivation are other common practices that have developed owing to the natural poverty of the soil and the inappropriate farming methods used. In the opinion of the Chief Native Commissioner, the communal system of land tenure is largely responsible for overstocking and the destruction of timber. Cattle tracks (a consequence of overstocking) and roads also cause serious erosion losses.

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*We are indebted to the Chief Chemist of the Department of Agriculture for procuring for us much of the information contained in this section.

Indeed, the wagon roads made for the transport of wood have been more harmful than the actual destruction of trees (3). It is hoped that the increasing use of crude-oil engines and of more efficient furnaces by tobacco farmers will do something to relieve the situation.

Propaganda against erosion was initiated in 1921, but little organized work was done until 1929. Since then, the following progress in land protection has been made under the aegis of the Agricultural Department.

Year	Miles of Ridge Terracing	Approximate Acreage of Land Protected
1929	76	2,280
1930	103	3,090
1931	150	4,500
1932	108	3,240
1933	132	3,960
1934	126	3,780
1935	367	11,040
1936	535	13,375*
Totals	1,597	45,265

(*Based on 25 acres per mile of ridge instead of 30 acres per mile, as in previous years).

Besides contour-ridging, the construction of storm drains above cultivated land is recommended to catch water flowing off the veld (1).

Impetus was given to the conservation movement by publication in 1932 of the Report of the Soil Erosion Committee appointed by the Rhodesian Agricultural Union. The Report stressed the need for national action and recommended the establishment of District Soil Conservation Boards co-ordinated under a Central Soil Conservation Advisory Council. As a result, Central Councils have been established in Salisbury and Bulawayo, and a system of district sub-committees has been formed. The various Government departments concerned, the railways and the farming community are represented on the Councils, so that co-operation between different interests is secured. A policy of decentralization is aimed at, in order to disseminate soil conservation principles as widely as possible. The Committee also recommended new and amended legislation which at the time of writing has not been brought into force, although a Soil Conservation Act is under consideration. Free technical assistance and advice are given to farmers by Government engineers, and financial advances for conservation and irrigation works are made on easy terms. The Agricultural Department issues, free, limited quantities of kudzu vine, spineless cactus and certain creeping grasses on condition that they are planted where excessive wash may cause erosion (e.g. contour-ridge outlets and drain discharges) (2).

In the native areas, nothing is left to individual enterprise in checking erosion. The Native Department employs a soil conservation officer and

a considerable staff of agricultural and erosion-control demonstrators whose work is both educative and constructional. The Department is progressing as rapidly as possible with contour ridging and draining on the worst eroded areas. About 6,000,000 acres have been mapped with regard to soils, vegetation, agricultural and grazing potentialities etc. on a scale of 1:60,000.

NORTHERN RHODESIA

Northern Rhodesia is sparsely settled by Europeans, and the greater part of it is under primeval forest. At present, erosion is not a pressing problem, but precautions in the way of conservation demonstrations and forest protection are being taken to guard against future eventualities. The soils are mainly Kalahari and granite sands which are said to be not very liable to erosion.

Stockdale (5) states that the traditional native agricultural system was one of "small farms cut out of the bush, but, with the introduction of ploughs, there has been a piecemeal departure from this system towards an imitation of the European farm. Erosion from small holdings of two to three acres in extent is insignificant, particularly if these are cut out of dense bush in which large numbers of tree stumps are left, but the loss of soil from ploughed farms of ten to twenty acres in extent, which have been established in open country so as to avoid the cost of stumping, is considerable. In the course of this transition, ploughing is frequently done up and down the slope, certain traditional crops abandoned, and other recognized native methods of cultivation changed. For example, the growing of finger millet has been abandoned for maize and the greater millets, as the bush areas have been left for the open country. Less groundnuts are being grown, and sweet potatoes instead of being planted on mounds are grown on the flat. The ploughing increases the run-off of water, and there are no tree-stumps to check the flow. There is more run-off in maize cultivations than in those of finger millet, and the departure from growing sweet potatoes on mounds is a mistake. The result of these changes is that soil erosion is becoming more serious, and unless some alteration in the system is effected devastation may result. It is not to be expected that a reversion to the traditional methods of the past will be either practicable or possible, and efforts must be directed towards building up, upon the basis of the now forsaken native methods, a system which will make continuous cultivation possible."

References (Rhodesia)

1. Rhodesia Agricultural Journal. The dangers of soil erosion and methods of prevention. *Rhod. agric. J.* **32.** 533-42. 1935.
2. ———— Free issues to check soil erosion. *Rhod. agric. J.* **34.** 6. 1937.
3. ———— Soil conservation. *Rhod. agric. J.* **34.** 90-120. 1937.
4. Rhodesia Herald, March 12, 1937.
5. Stockdale, F. A. Soil erosion. *Emp. Cott. Gr. Rev.* **12.** 1-8. 1935.

East Africa

TANGANYIKA

The most up-to-date information on the erosion problem in Tanganyika is available in a special memorandum published by the Director of Agriculture on behalf of the main departments concerned, namely, the Forestry, Veterinary, Education and Agricultural Departments, and the Provincial Administrations, whose officers have assisted in carrying out valuable work in the field. Reports of work done, action taken and results achieved have been received from all the above and incorporated in this publication, which represents a review of the position up to June 30, 1937.

Reference should also be made to the annual reports of the Department of Veterinary Science and Animal Husbandry for 1931, 1933, 1934 and 1935 (9) for particular reference to progress with the problem of overstocking in its relation to erosion in Tanganyika. Some results given in the 1935 Report are dealt with at the end of this review of the position.

Questions relating to a number of aspects of erosion control have been mentioned in the annual reports of the Department of Agriculture for the years 1931-36 (10). The preliminary results of the soil erosion demonstration at the Coffee Research Station, Moshi, are also discussed briefly in this review.

The process of soil erosion is not the same throughout the Territory; for example, the problem on Kilimanjaro and other mountainous areas is to cope with heavy rainfall on steeply sloping land. That of Sukumaland is more varied and difficult; here the conditions are semi-arid with soil desiccation and wind erosion over a long period of the year, as well as sheet erosion during the heavy rains. Hence control measures vary with district and also with the nature of the soil.

When during 1930 to 1931 a policy was being formulated, the recommendations of the Ceylon Soil Erosion Committee were carefully studied and in particular the recommendation that "after educative methods have been tried for seven years, the subject should be brought up for review on the understanding that, if conditions are still unsatisfactory, compulsion by means of legislation should be further considered."

In 1931 a large committee was formed under the chairmanship of the Director of Amani to advise on the problem of soil erosion. This committee also concluded that in the absence of sufficient funds for a direct attack on the problem the endeavour should be primarily educative rather than directly ameliorative. While Government was prepared through its officers to demonstrate methods and systems for arresting erosion, it was not prepared to carry out extensive works, either to prevent erosion or to check deterioration in eroding areas.

This decision required that field officers of the Agricultural, Forestry and Veterinary Departments should first carry out propaganda and should demonstrate the proper management of land and the measures necessary to minimize loss of soil by erosion. Anti-erosion methods should be included in the school curriculum by the Department of Education. Forestry Officers should encourage the planting of windbreaks and wood lots where necessary, they were to impress on the people the need for the preservation of natural forest growth and vegetation on the crests and steep slopes of hills and along water courses. Veterinary officers were to point out the risks of over-stocking, the value of rotational grazing, the utilization of plant residues as stock food and the value of multiplying watering places for stock. Officers of the Public Works Department and the Railways were requested to adopt erosion control measures in lay-out and construction. Agricultural Officers were instructed to demonstrate and preach the value of soil cover, planting and cultivation on the contour, the use of terracing and anti-erosion banks, contour weed lines, contour strips of undisturbed land, protection of trees and so forth. All these efforts were to be focused by the Administrative Officers, who were to bring clearly to the notice of the people the real meaning of erosion and the value of the efforts of the individual cultivator to the clan and its land.

It is now claimed that people are becoming interested, some tribes and clans are convinced of the need for soil conservation and in due course desirable agricultural practices may be carried out as routine and custom. Possibly sooner or later general legislative measures may be necessary to bring a minority into line, but it is stressed that the time must be ripe before enforcement is applied generally by means of a territorial law. Meanwhile anti-soil-erosion rules under the Native Authorities are being encouraged.

While appreciating the losses suffered by individuals through erosion and the danger to tribes and to water supplies in certain areas, it must be realized that the whole territory is not seriously endangered by man's disturbance of the land, for the total cultivated or exposed soil area is only about one-thirtieth of the whole. It is stated that 7 per cent of the area of the territory is suffering from over-stocking. Thus at the outside only one-tenth of the area of Tanganyika Territory is affected, and some of that one-tenth is not really menaced. With so little proportionate disturbance and considering the natural regeneration of which vegetation is capable over the greater part of tropical Africa it is unduly pessimistic to be gloomy about the condition of the whole Territory. Nevertheless it should be realized that this one-tenth undoubtedly represents by far the most valuable fraction of the country.

As the result of this intensive propaganda Native Authorities are now beginning to apply cultivation and grazing rules ; in some instances with one or two crops only, in others generally for application in specific areas and yet in others of general application in the tribe or area. Examples of some local regulations are given as appendices in the memorandum under

review. If the rules become completely effective within a period of 7 to 10 years and if, as is expected, they become customary a great stride will have been taken. The rules are regarded mainly as a means of supporting local propaganda and administration, but in some areas penalties for non-compliance are now exacted.

In almost every district of the Territory the cultivator has been shown how to reduce erosion to a practical minimum. Methods have been devised, varying with climate, soil and existing cultivation practices, which operate to impede the flow of water and the movement of soil. Trials will continue until the most feasible and practical measures to suit the diverse conditions of the many different areas of the Territory are known. Traditional tribal customs are sometimes most useful and are taken advantage of; for example, *mtuta* or native ridge cultivation provides a greater surface for water absorption, whatever the direction of the *mtuta* lines (8). It has been a simple matter to demonstrate the value of the *mtuta* when used as a contour ridge and then to go one step further by making cross-checks of soil in the gutters between the ridges. Again, it was not difficult in some parts of the Territory to demonstrate that native cultivators there had evolved systems of land management which were practically ideal counters to water erosion. It is known, therefore, that where it is essential intelligent cultivators can work the land without soil loss. Nor was it difficult to induce sound systems of soil management where a new crop was introduced. It was not, however, easy at once to apply all the schemes and desirable practices over enormous areas. Injudicious grass burning on hillsides may be casual yet in the aggregate extensive, leading to the destruction of forest; over-grazing and trampling by stock, failure to plant trees, and shifting cultivation especially on steep slopes are all real difficulties which can be overcome only gradually. On the other hand, some Native Authorities have been induced to plant wind-breaks across the country, others to adopting contour wind-breaks, and others to declare hillsides and hilltops as reserves not to be cultivated and to be grazed only during defined periods.

Before proceeding to give the reaction of the people of the various Provinces to the propaganda for the conservation of soil, forest and water resources, the memorandum quotes the views of the Director of Veterinary Service (H. E. Hornby) on the question of over-stocking (5 and 6). This is done in view of the importance of this particular problem in the Lake and Central Provinces. According to this author the fact that erosion is the direct result of over-stocking has attracted so much attention that there is a danger of loss of perspective. Soil erosion is not synonymous with over-stocking; it may be due to many factors of which an important one is over-stocking.

From the purely native point of view over-stocking may even be a necessary evil, essential to maintain a high standard of health among the native herds and often used deliberately from time immemorial. The effect of government by Europeans has been increased peace and security

with much improved opportunities for accumulating stock, the direct result of which is the over-stocking so prevalent to-day. Because over-stocking inevitably tends to produce aridity and to reduce the incidence of certain diseases, native stock owners may favour it, preferring seasonal losses from starvation, which they can understand, to continual and greater losses from diseases, the nature of which is beyond their comprehension. This state of affairs, which will never rectify itself, he summarizes as follows :—

" (a) Many traditional native husbandry methods are inseparable from local over-stocking with the attendant risk of soil erosion.

(b) This deteriorative process is accelerated by *laisser-faire*.

(c) The only hope of checking this growing evil lies in some form of government intervention."

About 40,000 sq. miles of the Territory are stocked to saturation; probably 25,000 of these are over-stocked, including what was some of the best land of the Lake, Central, Northern and Western Provinces, that is, about 7 per cent of the total area of the Territory. It has been calculated that this over-stocked area is still capable of carrying satisfactorily upwards of two million cattle, together with nearly the same number of sheep and goats, but actually the area is maintaining half as many again. " In spite of his abuse of his heritage, the native is more important than the land, and in spite of soil erosion domestic animals are among a country's most important assets. If we interfere, we must do so judiciously and, by using knowledge beyond that possessed by the native, be sure that removal of the reproach of over-stocking benefits not merely the land, but the stock and people as well."

Hornby (loc. cit.) outlines a scheme to relieve overstocking by the expansion of a rotational grazing system, the multiplication of water supplies, the control of grass burning, and a control of the type and numbers of stock which may use each of the units of grazing which would be demarcated and developed. It is to the institution of rotational grazing that the utmost importance is attached. The department authorities wish to see enforced the compulsory putting out of bounds to stock during the rainy season of any piece of land which is being eroded through over-stocking. In fairness to the native he must at the same time be shown where he can graze his animals, and this means the use of suitable systems of deferred grazing and in some instances provision of new grazing lands through dam-building and tsetse-reclamation (1).

The work of the Tsetse Research Department is of importance in connexion with soil erosion. There are many areas in the Central Provinces, especially where tsetse has encroached on cattle grazing lands and driven the stock back into what was already over-stocked land; again the tsetse is delaying the spread of people from certain over-populated areas. At the same time the presence of tsetse in many parts may be a blessing in disguise, as it can be regarded as acting as the trustee of the land for future generations.

The tsetse research work has enabled the Department of Agriculture in consultation with the Field Departments to formulate and carry out schemes for the elimination of tsetse from blocks of land adjacent to over-populated areas, and their settlement and development on lines which will preserve the land and its water supplies.

The memorandum under review concludes with a detailed statement of the position in the various Provinces of Tanganyika Territory. A similar statement is contained in a " Memorandum on measures taken in various Provinces in 1933 and 1934 in connexion with soil erosion " (4).

Brief reference is made by Stockdale (3) to the present position in Tanganyika ; there are undoubtedly large areas where erosion has become so serious that reclamation would not be economic, while the position is becoming serious in the Uluguru mountains. Considerable sections of the pastoral areas in the Territory have been severely eroded, due to overstocking consequent upon over-concentration of stock around the available water supplies. Rotational grazing is giving encouraging results and the position may also be relieved by provision of additional water supplies. Erosion on the slopes of Kilimanjaro is being successfully checked by contour hedges and banks. Stockdale states that Tanganyika is fortunate from the land point of view ; considerable stretches of fertile land are still available, as four-fifths of the Territory is infested with the tsetse fly. This country can be won by close settlement from the fly, and a beginning has already been made under well-conceived schemes of peasant holdings. Definite soil conservation rules have been enacted by a number of Native Authorities ; examples of these are given.

As already noted, soil conservation began to be discussed in the reports of the Department of Agriculture in 1931, when reference was made to demonstration plots of terracing, contour trenching, etc., to the values of cover crops and green manures, and to the " soiling system " of feeding cattle. The 1931 report also referred to the need of shelterbelts and windbreaks in certain cotton-growing areas, as high winds are prevalent in June and July when the cotton bolls are bursting. *Cassia siamea* is used.

In 1932, it was stated that soil erosion overshadows all other factors as far as the highlands are concerned ; again it is suggested that stall-feeding of cattle should be more widely adopted and that edible canna or certain cover and green manure crops should be used as fodder, to avoid the transport of grass for long distances.

In the introduction of conservation practices it has been more difficult to achieve innovations with long-established food crops than with economic crops such as coffee which are recent enough to be free from tradition or tribal custom (1934 report).

The drying up of certain springs and rivers is reported in the same year as due to deforestation rather than to deficient rainfall. It is considered that irrigation has been grossly overdone in the past and has led to the loss of much valuable topsoil. With the exception of the low rainfall area of the west of Kilimanjaro, only a skilful and moderate application of irrigation water is recommended, but it is not essential.

The 1934 report also describes the formation of native holdings, the object being to establish a class of native smallholders who would farm the land according to the methods recommended by the Department's experiment stations and demonstration farms. The preliminary results were satisfactory and it was concluded that an eight to ten-acre holding is sufficient for the present requirements of a native family of three working units with a limited number of stock, but that a further ten acres per family should be held in reserve.

The extension of peasant holdings and stall feeding of cattle is again quoted in the 1935 Report as a valuable approach to the problem of overstocking in the Lake Province.

In 1934 a demonstration consisting of a series of eight plots, each 100 feet by 14 feet 9 inches on a uniform slope of 1 in 6 was laid out on land newly cleared from heavy (probably virgin) bush at the Coffee Research Station, Lyamungo, Moshi (2 and 7). Records were taken of soil loss and water run-off. Of the various treatments tested as to their value for soil conservation on coffee plantations, the following were found to be effective under the local conditions : (1) contour ridges at 1 to 1.5 ft. vertically between the ridges, (2) *Crotalaria* hedge on contour and cover crop, (3) cover crop (procumbent), (4) erect cover crop, (5) banana mulch, (6) terracing, (7) box ridging on contour. Of these methods, Nos. 1, 2, 3 and 4 do not adversely affect soil moisture during drought. The conclusions drawn are that conservation measures are necessary, and that contour ridging is the cheapest effective method in coffee ; terracing appears to be unnecessary on a 1 in 6 slope and box ridging has no particular advantages. Banana mulching is as effective as any measure and also conserves moisture ; further experiments are in progress with this method, which is a simple native practice.

Some preliminary data on run-off and erosion in semi-arid Tanganyika are being obtained from plots at Mpwapwa (8).

Mpwapwa is well situated for tests of run-off and soil loss under varying systems of cultivation. The average rainfall for the last ten seasons, July to June, is approximately 26 inches per annum. The distribution is typical of the semi-arid areas of the Territory, that is, it is seasonal (from about December to April) and the greater part falls in torrential downpours which in exceptional cases may be as much as 3 inches per hour. With an adequate vegetation cover, however, the rainfall even at its heaviest appears to penetrate satisfactorily into the soil, but when this cover is seriously impaired by over-stocking or the land is under faulty cultivation damage through erosion tends to become unusually severe.

The soil type of these tests was described by G. Milne of the East African Research Station, Amani (see 8, p. 134) as "a coarse-sandy friable loam. Clods are brittle with a highly porous structure, which is evidenced also by the hollow sound heard on striking any part of the wall of the pit with a hammer. The soil was dry (at the end of the dry season) to the full

depth of the pit (6 feet) but with no cracking or fissuring." The percentage of clay from a sample of the top 6 inches of soil is given as 33 and the silica-sesquioxide ratio is 1.92 (indicating low laterization).

According to Staples, of the three main soil types in the vicinity of Mpwapwa the type on the run-off plots is least erodible. It is probably also superior to the granitic sands so prevalent in semi-arid Tanganyika, or even the red lateritic soil of the moister southern highlands, when the grass roots have disappeared as the result of two or three years of cultivation. The volcanic soils of the Northern Provinces and the red loams of the coastal belt will, however, probably be found to be considerably less erodible.

The slope on the first six plots is 6.6 per cent and uniform throughout ; the seventh and eighth plots, which have only recently been added to the experiment in order to obtain data from land under the natural vegetation, deciduous thicket, the most important climax vegetation type of the area, have a slope of 7.8 per cent.

Run-off and soil loss from plots at Mpwapwa, 1933-34 and 1934-35

Plot No.	Treatment	Percentage run-off		Soil loss Tons per acre	
		1933–34	1934–35	1933-34	1934–35
1.	Bare ; uncultivated	52.9	47.8	56.85	59.92
2.	Bare ; flat cultivated	34.8	28.2	48.82	54.64
3.	Bare ; ridge cultivated	25.2	20.8	12.71*	27.14
4.	Bulrush millet (1933-34) and *mlama* (1934-35)	29.1	22.9	40.35	34.35
5.	Perennial grass	2.8	0.9	—	—
6.	Bare ; flat cultivated	33.3	27.1	22.78	15.17
7.	Deciduous thicket ..... A.	—	0.5	—	—
8.	Ditto. ..... B.	—	0.4	—	—

*This figure is for soil lost with slightly less than half of the season's rainfall.

Rainfall in mm. { 1933-34 = 675 ; 1934-35 = 564

In conclusion, some reference should be made to the administrative problem ; in this Territory and others where overstocking is a serious menace, some method of limiting, probably by legislative action, the

numbers of stock in accordance with the carrying capacity of the pastures is essential.

What is required in cultivated lands is not so much experimental work which demonstrates the fact that there is erosion and that certain action checks it, but rather a series of demonstrations in affected areas, simple, repeatable and cheap. In many areas nature herself can check erosion if permitted to act, and if the causes of erosion are reduced. It is considered that the subject is exhausted by discussion and that what is required is action on feasible lines.

References (Tanganyika)

1. Aberystwyth, Imperial Bureau of Pastures and Forage Crops. Correspondence on soil erosion in Tanganyika Territory from H. E. Hornby. Director of Veterinary Services. Mpwapwa, 20 February, 1937. pp. 3.
2. East African Agricultural Journal. Preliminary notes on the soil erosion demonstration at the Coffee Research Station, Lyamungu, Moshi. [By the Staff.] *E. Afr. Agric. J.* **1.** 236-40. 1935.
3. England and Wales, Colonial Advisory Council of Agriculture and Animal Health. C.A.C. 345. Report by Sir Frank Stockdale on his visit to East Africa, January-March, 1937. London, 1937. pp. 117.
4. England, H.M. Government. Colonial Report No. 105 to Council of the League of Nations on Tanganyika Territory for the year 1934. London, 1935. pp. 201.
5. Hornby, H. E. The control of animal diseases in relation to overstocking and soil erosion. *Emp. J. exp. Agric.* **5.** 143-54. 1937.
6. ———————— Overstocking in Tanganyika Territory. *E. Afr. Agric. J.* **1.** 353-60. 1936.
7. Sanders, F. R. Notes on the soil erosion demonstration at the Coffee Research Station. Lyamunga, Moshi. *Planter.* 1937 (August). pp. 5 and 13.
8. Staples, R. R. Run-off and soil erosion tests in semi-arid Tanganyika territory. Second report. *Rep. Dept. Vet. Sci. Tanganyika.* 1935. pp. 134-41. Dar-es-Salaam, 1936.
9. Tanganyika Territory, Department of Veterinary Science and Animal Husbandry. Annual Reports. Dar-es-Salaam, 1931, 1933, 1934 and 1935.
10. ———————— Department of Agriculture. Annual Reports. Dar-es-Salaam, 1931, pp. 42-3 and 73-4; 1932, pp. 6-7, 28-9 and 38; 1933, pp. 7 and 36; 1934, pp. 34-6; 1935, pp. 31 and 41-5; 1936, pp. 8-9, 43-5 and 66-7.

KENYA

Most of the reports which have so far appeared on the question of erosion and conservation in Kenya have discussed the conditions in the Ukamba (Machakos) Reserve and the Kamasia Reserve, which have received more attention on account of their accessibility. Maher (3) states that parts of the Kitui Reserve are equally bad, while the situation in parts of the Emba Reserve is as serious as anywhere in the Colony.

The great majority of Kenya Colony (71 per cent) has a rainfall of under 30 inches, while only a small proportion (11 per cent) receives more

than 40 inches. Details may be obtained in the report by Lewis on "Irrigation; water supplies for stock, water law, etc.", December, 1925, and the rainfall map accompanying that report.

The desert spreads not so much through the influence of heat and aridity projected from existing deserts, as by destruction of vegetation through overstocking and fire by herdsmen and primitive agriculturists on the fringe of the desert. It is reported that the Turkana desert now to be surveyed by the Soil Conservation Service of Kenya is spreading outwards at the rate of six or seven miles per year.

Surveys have already been made in the Machakos, Kitui and Kamasia Reserves, all of which are on the borders of the high land with a higher rainfall; also of the West Suk Reserve which adjoins the settled area of Trans Nzoia, and of East Suk which, in common with large parts of the Elgeyo-Marakwet Reserve, is virtually a desert. The only other Reserve in the area around the settled areas is the Masai to the south; this tribe is almost entirely pastoral and erosion control is largely a matter of grazing control. There is in any case little erosion over vast areas of the Masai Reserve.

The higher rainfall areas include the fertile Kikuyu Reserve and the Reserves of the Kavirondo tribes which fall within the region affected by the Lake rains. The latter region is roughly a belt about 100 miles wide around Victoria-Nyanza. The effect of the lake in producing heavy local instability rains is clearly shown by the meteorological records. The Director of the British East African Meteorological Services is suggesting a scheme for the establishment of a forest belt several miles wide and about 100 miles long as an attempt to extend the area affected by the local instability rains. The Karamoja district in Uganda and the South Turkana and West Suk districts in Kenya would be the areas to receive most benefit if this afforestation had the desired result, namely, of pushing back the desert.

The deleterious effects of destruction of vegetation in the semi-arid areas is intensified by the occurrence of at least one and generally two severe dry seasons in the year. In the moister districts of the Kikuyu and Kavirondo Reserves erosion is continuing in many places at a very rapid rate, due to the increasing demands made by the people on the land owing to (a) increased population; (b) increased desire to obtain cash through the sale of crops; cotton is the cash crop most conducive to erosion, followed by maize; (c) the absence over large areas of a suitable mixed farming system; (d) the cultivation of hillside unsuitable for tillage; (e) lack of conservation measures in general; (f) concentration of stock in small areas; (g) sub-division and fragmentation of holdings under existing systems of land tenure.

In the European areas erosion is caused by exhaustion of the soil through long and continuous cropping without the adoption of measures to prevent erosion and maintain the humus content of the soil. The results of land misuse are only now becoming apparent in a grave form as much

of the land in the settled areas has been cultivated for only 15 to 25 years.

Some areas in Kenya have already reached a state of devastation such that nothing short of the expenditure of enormous and quite impossible sums of money could restore the land for human use above a bare and precarious subsistence standard. In such places the only practicable policy is likely to be the resettlement of the natives under strictly controlled settlement schemes in more favourable situations, such as has been done by the Government in Tanganyika. It is, however, evident that resettlement of natives from devastated areas is possible only to a limited degree and for a limited time in Kenya Colony, in which there are not vast areas of unpopulated lands such as occur in Tanganyika.

Generally speaking erosion in Kenya has become serious only during the past ten years, but there has been a marked acceleration during the past five years (14). In addition to the causes enumerated above, the locust invasions of 1929-30-31 and the drought of 1931-35 greatly accelerated the process and were largely responsible for making it so apparent in the space of a few years. There is evidence in the silt deposits south of Lake Baringo that there were periods of severe erosion in the watersheds long before the arrival of the Europeans. There is no doubt that the rate of erosion has increased within the last five years, due chiefly to long continued cultivation and to the protracted droughts; these droughts have always been a feature of the climate of large parts of the Colony, but under the original cover of vegetation their effects were not so severe. In most cases, however, it is fairly evident that erosion has become marked only since the coming of the European. This aspect is discussed by Beckley (11).

One of the major causes of erosion on individual European farms is the very large number of cattle and goats owned by "squatters" (resident native labourers); the problem of dealing with this squatter stock is very important in connexion with the control of overgrazing in European areas (2).

In the absence of measuring devices it is difficult to assess the rate of erosion; gulleys 2 to 3 feet deep have developed in a single season in cotton lands, while in maize the loss of an inch of soil in a single storm has been observed. The largest loss yet noted has been 12 inches of top soil in a year in a badly denuded area.

The first step in erosion control was the introduction of propaganda; it is claimed that the Europeans have become erosion conscious, although by no means all are taking steps to control it. It is difficult to make European farmers recognize that erosion is actually taking place on their land. Opinions differ as to whether the effects of propaganda will be sufficiently rapid to accomplish the desired results. D. C. Edwards (1) considers that it is necessary to apply methods on a very extensive scale through the tribal organizations; it is not sufficient to compel the natives to reduce their stock and to construct contour trenches on slopes in certain comparatively small areas, as is at present being done, or even in extensive

areas. By such methods there appears little hope of the retention of these areas in an improved condition as the work extends to larger tracts of land. Any form of policing will rapidly become impracticable and unless the scheme of improvement is based on tribal units which are taught to recognize some responsibility in the matter, reversion of the areas to the original degenerate condition will follow closely behind the forward movement of the Reconditioning Officer. A plan for the future management of the improved areas must become part of the tribal machinery if any lasting good is to be obtained. The initial requirement in the formulation of such a scheme is a thorough knowledge of the conditions of land tenure of every tribe concerned. Maher (3) states that under the policy of modified indirect rule, which is adopted in Kenya, all action is taken (as far as possible) through the Local Native Councils and the native executive officers. The chiefs or headmen were appointed either by Government or in some districts by popular choice. So it will be as regards the anti-erosion measures carried out under the Native Authority Ordinance (15). However, where the situation is desperate the time cannot be spared to await the enlightenment of the people and more direct action by Government may be needed, for example, in compulsory limitation of stock or compulsory resettlement in their own interests of people from badly eroded areas to areas in which they have more hope of attaining a reasonable standard of life. An understanding of native land tenure in the areas affected is necessary in that (a) reallotment of the lands may be necessary after extensive soil conservation measures, including engineering works, have been undertaken ; (b) sub-division and fragmentation of holdings must be prevented by a change of the customs of inheritance since these customs are contrary to the requirements of soil conservation and economic use ; (c) on the other hand consolidation of holdings to compact blocks of reasonable size must be arranged as and when possible. All Departments concerned in any way with soil conservation are doing what they can to stress the essential need for anti-erosion measures. The Administration and the Agricultural Department are collaborating closely. Forests under Government control are stated to be carefully regulated, but it is doubtful whether the Road Authorities really appreciate the dangers of soil erosion in their construction work.

With regard to anti-erosion work in native reserves the position at present is that no power exists for compulsory anti-erosion work, since no resolutions have been approved under the Native Authority Ordinance by the Governor in Council. Draft uniform resolutions are being prepared which it is hoped will be passed by each Local Native Council, and then approved by the Governor in Council. Numbers of natives are adopting soil conservation measures as a result of demonstrations on Local Native Council seed farms, although recognition of the problem by the natives is confined to certain progressive areas, e.g. parts of the Kikuyu Reserve. Over the majority of Kenya it is doubtful whether propaganda has yet had any effect. A sum of £2,500 has been allocated to the Department of

Agriculture for the formation of a Soil Conservation Service, from which it is proposed to use an allowance of £250 for propaganda. An informal Propaganda Committee meets occasionally in order to discuss and co-ordinate methods of propaganda. One of the first activities of this Committee was to arrange for a comprehensive course of talks on land utilization to be given in all European schools which are under Government control. An unofficial society, the Kenya Arbor Society, is also very active in attracting attention to the dangers of soil erosion (8).

According to the Department of Agriculture (14) too great an emphasis cannot be laid on the danger of over-stocking, especially by goats, which cause great damage to young growth, particularly on steep slopes. Among primitive peoples, both pastoral and agricultural, wealth lies in possession of large flocks and herds. Barter for the few luxuries, for example, blankets or aluminium pans, was usually in terms of stock; goats, sheep, cattle or camels. The bride price and the compensation for the loss of a productive member of the family are even now almost universally paid in stock. Among some agricultural peoples land could be rented by the payment of a number of small stock, usually goats; on abandoning the lease the same number were returned, the real rental being the increase only. In these circumstances it is not surprising that numbers rather than quality of stock have been and still are regarded almost with veneration. Before the coming of the Europeans, raiding distributed stock from areas where they had accumulated to areas where they were relatively scarce; it did not reduce their numbers except insofar as it spread disease. Numerous increases in stock numbers have, therefore, followed the stopping of these raids and the protection of native herds against disease. The first effect has been a depreciation in quality, partly due to indiscriminate breeding, partly due to lack of new blood and partly to hunger. The second effect has been denudation, due mainly to mechanical destruction of the vegetal cover.

While the pastoral tribes had no use for currency and their diet consisted of blood and milk, there was little prospect of any voluntary reduction in stock numbers. It is claimed that, as the advantages of currency are being realized, there is some prospect of voluntary sale from the more heavily stocked areas, but there would appear to be some doubt regarding this situation. E. Huxley (2) states that pastoral tribes display considerable reluctance to sell their stock and doubts have even been expressed as to whether the supply of cattle required by the new Liebig factory at Athi River—estimated at 30,000 head a year— can be maintained indefinitely without the use of some measure of active persuasion. The price of cattle is at present high (3) but it will fall when compulsory culling of cattle begins under the Yatta rules, which were to become operative in November, 1937 (16). Cattle sales will be organized, but Leibig's will compete with other buyers.

D. C. Edwards (1) states that it is doubtful whether the Masai will suddenly develop a commercial outlook merely because an outlet for their

cattle has been provided, but there are, of course, other sources of supply. The change may be brought about, and possibly will have to be in the long run, by the more gradual process of the encouragement of Indian traders in the area, which will induce the desire for money in order to purchase trade goods. Maher (3) states that the Masai tribe is apt to be given an importance which their numbers do not justify. There are estimated to be about 52,000 of these natives, in a total of over three million natives in Kenya, while large areas of their country are relatively flat and not highly erodible, particularly where the soil is a porous, volcanic ash. Local erosion does occur around the water supplies.

The two main factors which are considered to be influencing the need for currency are education in the production of ghee, which applies chiefly to the Masai, and the consumption of vegetable foods. The former brings in ready money and is teaching the native to appreciate the better producing animal ; the latter requires money for purchase. There is one danger, however ; the demand will be mainly for cattle and thus the goat may tend to show a disproportionate increase. Shade-drying of goats' skins is being introduced and this will lead to an increase in the price received for the skins. It is not considered, however, that this industry will lead to any diminution in the goat population ; it might conceivably lead to a greater appreciation than ever, in native eyes, of the value of the goat. Some authorities consider that it may be a mistake to encourage a trade in goats as some pastoral tribes own very few at present. The use of cattle for bride price may be regarded as connected with religious beliefs, but there is one case where religious beliefs have had a positive bearing on erosion control. Much of the Ukamba Reserve is quite devoid of trees, except for the trees and patches of trees which are regarded as sacred ; only in those very small areas is the full soil profile still present.

Locusts have been responsible for much denudation, which has led to greatly accelerated erosion. The grass has been completely cleared and has failed to recover before the next rains ; opinions differ as to whether this is due to accelerated evaporation from the bared soil, or to some toxic effect caused by the locusts. Maher states that this toxic effect has not been proved and believes that the very close biting which is done by these insects and the removal of the growing points of the grass, followed by the exposure of the soil and the close-bitten vegetation to the heat of the sun, are sufficient to account for the set-back which the herbage receives, especially when the areas which have been eaten down are given no respite by the cattle and goats. There have been examples where the combined effect of locusts and goats has resulted in the loss of a foot of surface soil in a single rainy season.

Soils

Erosion has been most severe on soils of low cohesion, such as sandy loams, silts and volcanic ashes, low in humus (14). The former tend to run together under rain, forming an almost impervious surface, which

facilitates a heavy run-off. Loams containing non-lateritic clay, if denuded, tend to suffer from sheet and gully erosion. Red lateritic loams from fairly high altitudes, 5,000 to 7,000 ft., which develop an "apparent sandy" or "psuedo-sandy" structure are liable to suffer from sheet erosion (17).

The subsoil when exposed develops a tile-like structure, each piece being several centimetres across; the individual particles are firmly cemented together. Gully erosion is never severe or spectacular.

Grassland areas, usually on black earths, juvenile red earths, red calcareous soils, etc., suffer severely from sheet and gully erosion when denuded by overstocking. Some of the most spectacular sheet and gully erosion observed in Kenya was in a denuded area where the soils are comparatively juvenile, or are derived from silts. A dangerous form of erosion has been observed in high altitude grass downs, where the soil is a red earth which has not yet been investigated. Although there is a dense growth of grass, "headland" erosion is eating rapidly into the hillsides; gully erosion by head erosion may be seen on many hillsides such as on the slopes of Mount Kenya and elsewhere. It is often difficult to understand how this erosion spreads, or what causes it. Maher considers that areas in which it occurs were originally under forest and that the grass cover in these situations does not seem to be sufficient to prevent erosion; there may possibly be some slipping of the top rain-soaked soil over the harder drier subsoil or rock.

A very insidious type of erosion occurs on the sandy clays of the coastal region, soils which have been tentatively classified as mottled clays. Soil is not transported as a whole, but the finer portions disperse readily in the rainwater and are carried away in the run-off, leaving behind infertile white sand. There is nothing spectacular beyond the staining of the rivers, but in a very short time the land becomes incapable of carrying crops. The erosion here is a replication, on a catastrophic scale, of the lateral removal of the finer fractions from soils derived from clays recorded by Robinson (19).

Although high winds are not usual in most parts of Kenya, wind erosion is becoming noticeable on many denuded soils. High winds do occur in the Northern Frontier Province, where a very strong south-east wind blows almost continuously, and is considered to have caused much wind erosion. Among the soils most liable are sandy loams, lacustrine deposits, and those soils which tend to pulverize on drying, the black earths. The main transporting agent is the dust devil; as many as twenty-five have been seen at one time, all probably originating on a patch of completely denuded land. It is considered that with increasing denudation whirlwinds become more and more frequent, local overheating of the air over a patch of bare soil giving rise to them. Some of these dust devils are of astonishing size and transport quantities of soil; the aggregate over a few years is considerable.

Erosion Survey

Support was given at the Second Conference of East African Agricultural and Soil Chemists, 1934 (5) to the principle of making surveys before framing policies; there was need for a field survey of eroded and potentially erodible areas, in which not only the present intensity of damage should be reported upon by agricultural officers, on the lines of the Kenya survey as described by G. H. Gethin Jones, but also the soil profile and all the factors associated in its development should be made a primary object of study by qualified soil scientists. (This survey has not actually been carried out, largely owing to the absence of replies from agricultural officers. The only organized survey now being carried out is that conducted by Maher, of one reserve after another.) The scheme of the Kenya survey is published in the Conference Report as a guide when erosion surveys came to be organized in other territories. It was suggested that a fifth class of land which should be added to the four described below was land drowned by material derived from eroded ground.

The following classification of eroded lands (figures to be quantitative in surface area) is proposed by Gethin Jones :

(1) No erosion or very slight sheet erosion not leading to reduction in crop-carrying capacity, provided the land is allowed to revert to bush at suitable intervals. Loss up to ten tons of soil per acre per annum, equivalent to 7 inches of surface soil per 100 years of cultivation.

Maher (3) states that it is impossible to allow land to revert to bush at suitable intervals with an increasing population and with the greater urge to cultivate which the natives are apt to develop under the impact of civilization. An attempt is being made to introduce a permanent and organized mixed farming system to replace shifting cultivation. There are very few areas in the Native Reserves where annual losses of less than 10 tons of soil per acre might not be expected, unless the soil was virgin soil quite recently, but even if the quantitative loss is small the qualitative loss of the valuable clay and silt fractions is high.)

(2) Slight erosion such that reduction in crop-carrying capacity occurs, due to mechanical loss of soil rather than to exhaustion of chemical fertility. Loss 10 to 40 tons of soil per acre per annum, equivalent to 7 inches of surface soil per 25 years of cultivation. Very large areas under native cultivation on fair slopes would fall into this class.

(3) Marked surface erosion, such that the land loses much of the surface soil within a few seasons whenever the natural vegetal covering is broken up by cultivation. Such land requires a prolonged rest for a period from 10 to 30 years before it can build up sufficient new surface soil to carry even a second rate crop. Loss may be 200 tons per acre per annum, equivalent to 7 inches of surface soil per five years of cultivation. Local areas on very steep slopes fall into this class, also less steep slopes where other factors, such as extreme erodibility, are concerned.

(4) Spectacular gully erosion causing the land to be so truncated that only a weak vegetal covering, if any, can be supported after a pro-

longed rest. Less serious erosion on shallow soils, with a good depth of sub-soil as parent material for a new top soil, also falls into this category.

Forests and Climate in East Africa

The influence of forests on climate and water supply in Kenya is fully discussed by J. W. Nicholson (10 and 18), some of whose conclusions may be quoted :

(1) There are certain parts of the world, including at least parts of Kenya and Uganda, where the total rainfall is likely to be affected by changes in the covering of vegetation, not only appreciably but possibly enormously.

(2) In East Africa trees and deep-rooted shrubs contribute more moisture to the air than herbaceous vegetation or bare soil and they are, therefore, more likely to influence rainfall than the latter type of vegetation.

(3) Under favourable circumstances, mountain forests in East Africa can induce occult precipitation up to at least 25 per cent of the total annual rainfall. Occult precipitation, namely, deposit of moisture from fog or dew, is due to the condensing capacity of forests and to the mechanical action of the trees themselves. When a cloud in the mountains passes through a forest the branches and leaves of the trees retard its movement and it goes into a state when it can no longer retain its moisture in suspension.

(4) Forests have little or no influence on cyclonic rain and the problem does not concern Kenya.

(5) In the case of monsoon rainfall, the local effect of forests on rainfall is limited to a maximum of about 3 per cent, but the regional effect may be far greater.

(6) Wherever meteorological conditions in East Africa are favourable to the production of instability rain, the possibility and quantity of such rain are greatly increased by the presence of forests. Instability rain is due " to the warming up of a surface layer of air to a point at which it is potentially higher than the air above it. The potentially light air begins to rise, at first in thin threads, which produce scattered cumulus clouds and finally, if the process continues far enough, in thicker columns which cause cumulo-nimbus clouds, with rain and perhaps thunder and hail. The potential density of the air depends mainly on its temperature and partly also on its humidity." In East Africa this type of rainfall is always very local in its distribution and in some parts of Uganda, to lessen the risks of crops failing, the natives cultivate two areas some miles apart from one another.

If accepted, these conclusions would suggest the advisability of considering extensive reforestation in Kenya ; even if they are not accepted in full, there is obviously wide scope for reforestation in selected areas, and for the use of trees as windbreaks in agricultural land. Only 2.65 per cent of the area of Kenya is under forest.

Grassland Types

The grassland types in Kenya are described by Edwards (6) who recognizes two main types, consisting of vast areas of acacia-grass savanna and comparatively small areas under the more favourable moisture conditions of the high altitudes. The latter type contains the high moisture and low temperature areas, where kikuyu grass (*Pennisetum clandestinum*) exists naturally or can be developed, and the intermediate zone, where moisture conditions are comparatively high, but where kikuyu grass is not important in the natural vegetation and does not succeed under cultivation, apparently as the result of the higher temperatures which occur.

In the intermediate areas, where an effort is being made to change from maize cultivation to mixed farming, one of the necessities is the provision of suitable grasses and legumes for sowing in these old arable areas.

The acacia-grass savanna areas occur under a low (20 to 25 inches per annum) and erratic rainfall, with prolonged droughts, and are the most important as regards area covered. They are occupied by native pastoral tribes and to some extent by European farms. In this type of country stock-farming, even under European management, must remain on extensive lines ; the main line of development must be controlled grazing to prevent deterioration from localized over-grazing and the conservation of fodder as hay or silage.

Suggestions have been made for a scheme of control for the drier areas occupied by native tribes, entailing the protection of areas in rotation, based on a knowledge of the periods required by the main herbage species to ripen seed. The areas would be demarcated by geographical boundaries, and would be protected in turn for a succession of seasons until after the seed has ripened, when they would be thrown open to grazing each season. In this way the whole of any given area would be utilized and the periods of protection would be only a month or two in duration each season. Since two periods of seed production per annum would occur over the greater part of the country, fairly rapid regeneration could be expected.

It is believed that the principle of rotation protection may be applied to the stock-owning native tribes. Although rigid control would be required, no fundamental changes of custom are necessary ; with a nomadic tribe, it merely means control of nomadism.

In the opinion of D.C. Edwards (1) extensive terracing and trenching are not practicable and these measures should be confined to the actual areas of cultivation. The mere closing of areas to grazing during one growing season has resulted in marked improvement and closing in rotation for a succession of growing seasons with grazing during the other part of the year would probably be an adequate means of improvement in many cases and one which would appear more practicable. It is expected that this method will be more effective than complete closure for prolonged periods, because of the necessity in some areas to assist the planting of the seed produced on the hard denuded ground surface. Trampling by cattle in the dry season would probably effect this. Such a method of rotational

management would not cease with the production of an improved condition, but would remain as part of the tribal organization of controlled communal grazing. Up to the present time no trial of this method, which is based upon the American scheme of deferred grazing, has been made, mainly because of the imperfect knowledge of native land tenure in the areas where it might be applied. Reforestation is essential in certain parts of the country, but steps to arrest the present trend of events cannot await that process.

Conservation in Kenya

The attempts to combat erosion in Kenya Colony may be divided into (a) propaganda, written or verbal, (b) demonstrations, (c) advisory services, (d) scientific services.

The perils of soil erosion have been stressed in several Bulletins issued by the Department of Agriculture (11, 12 and 13). The Kenya Land Commission of 1933 (Chairman: Sir Morris Carter) stressed the menace of erosion and over-stocking in many paragraphs of their Report. The absolute necessity of preserving the forests of Kenya, owing to their relation to rainfall, climate and soil fertility has been stressed in the Bulletins of the Department of Agriculture, and by D. E. Hutchins (4), R. S. Troup (9), J. W. Nicholson (10 and 18, etc.) as well as in various press articles published by the Kenya Arbor Society. Demonstrations of Mangum broad base terraces on arable land have been established for the benefit of European farmers, as well as examples of anti-erosion measures on coffee plantations. The conservation of soil and soil fertility on coffee estates is discussed by Gethin Jones (7).

Conservation propaganda has also been actively carried on in native areas where methods adopted and recommended include the construction of terraces of different types (broadbase, narrow base, bench and staggered), grassing and tree-planting on severe slopes, control of grass and bush burning, bunching of storm ditches, avoidance of destruction of vegetable matter and the use of crop residues, etc. for wash-stops, stone-terracing, culling of useless cattle, use of rotations and inter-planted crops and of compost. The total amount of work done, however, has not actually been very large. It is hoped that progress will be made when the necessary compulsory legislation has been obtained. In many instances additional funds are essential if work is to proceed upon the scale which is required.

Reconditioning officers have been engaged in certain districts by Local Native Councils; an experiment and demonstration have been in progress near Machakos since 1932. It is proposed, provided the necessary funds are available, to carry out a complete land utilization and conservation demonstration on 100,000 acres at Matungulu. Several other Local Native Councils have engaged Reconditioning Officers but their work at present is apt to be lacking in technical control and they are unable to devote their full time to soil conservation.

The Director of Agriculture concludes that it would appear that a great deal of erosion control is already being done in Kenya, but that it is

evident to any observant traveller through the Colony that what is in progress is insufficiently co-ordinated and on too small a scale to keep pace with the deterioration of the country, and that the problem is quite untouched in many areas. The Department of Agriculture has treated the question of soil erosion as of great importance for many years, as far as its resources and scope would permit. It has also been obliged to keep in mind the immediate necessity for stimulating agricultural production in native and non-native areas, and the staff available has been very small for both immediate and long range duties.

" It is impossible to avoid the conclusion that a task of this magnitude must be a matter for the co-operation of all Government Departments and that the final responsibility for directing the many lines of attack on a vast social problem, and providing means for the executive departments to carry out their parts in the co-ordinated plan, must rest with the Administration of the Colony."

References (Kenya)

1. Aberystwyth, Imperial Bureau of Pastures and Forage Crops. Correspondence re soil erosion in Kenya, from D. C. Edwards, Bishop's Castle, 23 October, 1937, pp. 2, and Nairobi, 18 November, 1937, pp. 4.
2. ——— Correspondence and memorandum re soil erosion in Kenya, from E. Huxley. London, 27 October, 1937, pp. 7.
3. ——— Correspondence including memorandum re soil erosion in Kenya, from C. Maher. Nairobi, 18 November, 1937. pp. 9.
4. East Africa Protectorate. Report on the forests of British East Africa. By D. E. Hutchins. London, 1909. pp. 155.
5. East African Dependencies, Technical Conferences of. Proceedings of the Second Conference of East African Agricultural and Soil Chemists, held at Zanzibar, August 3 to 9, 1934. Nairobi, 1935. pp. 63.
6. Edwards, D. C. Report on grassland improvement in Kenya, 1934. *E. Afr. Agric. J.* **1.** 269-77 and 344. 1936.
7. Gethin-Jones, G. H. Conservation of soil fertility on coffee estates, with special references to anti-erosion methods. *E. Afr. Agric. J.* **1.** 456-62. 1936.
8. Kenya, Arbor Society. Pamphlet No. 2 of 1937. Deserts in the making. A study in the causes and effects of soil erosion. By R. Ward. Nairobi, 1937. pp. 15.
9. Kenya Colony. Report on forestry in Kenya Colony. By R. S. Troup. London, 1922. pp. 47. map.
10. ——— and Protectorate. Forest Department Pamphlet No. 2. The influence of forests on climate and water supply in Kenya. By J. W. Nicholson, with a foreword by A. Walter. Nairobi [1929]. pp. 40.
11. ——— Department of Agriculture. Bull. No. 4 of 1930. Soil deterioration in Kenya. By V. A. Beckley. Nairobi, 1930. pp. 18.
12. ——— Bull. No. 11 of 1932. Soil wash. By A. D. Trench. Nairobi, 1932. pp. 3.
13. ——— Bull. No. 1 of 1935. Soil erosion. By V. A. Beckley. Nairobi, 1935. pp. 78.

14. ———— Memorandum on soil erosion. [Nairobi] January, 1937. pp. 7.
15. ———— Ordinance No. 2 of 1937. An ordinance to make provision in regard to the powers and duties of native official headmen and local native councils and to provide for matters incidental thereto. Enacted by A. de Vins Wade. Nairobi, 1937. pp. 13.
16. ———— Government Notice No. 705. The crop production and live-stock ordinance, 1926. Rules. Nairobi, 1937. [Yatta Plains (Grazing Control) Rules, 1937.]
17. Mohr, E. C. J. De bodem der Tropen in het algemeen, en die van Nederlandsch-Indië in het bijzonder. [The soil of the tropics in general, and of the Netherland Indies in particular.] Vol. 1. Pt. 2. *Meded. kolon. Inst. Amst.* No. 31. 1933.
18. Nicholson, J. W. The influence of forests on climate and water supply in Kenya. *E. Afr. Agric. J.* **2.** 48-53, 164-70, and 226-40. 1936.
19. Robinson, G. W. Normal erosion as a factor in soil profile development. *Nature, Lond.* **137.** 950. 1936.

UGANDA

The principal factors causing the development of erosion in Uganda are summarized by W. S. Martin (2).

" Prior to British administration no crops were grown for export and cultivation was limited to the area necessary for food production. The banana-eating tribes cultivated gardens of often 3 to 5 acres in extent, but preserved them from erosion by mulching with leaves and split stems. They also cultivated small areas of subsidiary food crops, such as sweet potatoes and beans, but these were frequently grown together in the same plot and the soil was thus exposed for short periods only. Their implement was the primitive hand hoe, and the larger trees of the natural vegetation were rarely cut down. Their cultivations were scattered through the bush and the elephant grass, and under such conditions erosion was very limited. Similarly the grain-eating tribes cultivated small scattered patches ; although these were situated in areas of light, easily erodible soil, they were usually so small that neither wind nor water could effect erosion.

" With the advent of European administration tribal wars ceased. Medical and veterinary science controlled the diseases to a large extent, with the result that the human and animal population increased. Simultaneously trials of cash crops for export were made and 30 years ago it was becoming clear that cotton was the crop best suited to local conditions. At first the cotton plots were quite small and scattered in a manner similar to the food plots, but every plot of cotton represented an addition to the area cultivated. At first the native undertook the cultivation reluctantly and under official persuasion, but soon realized the advantages of money and gradually became accustomed to new standards of luxury. To achieve and retain these and to pay his taxes he gradually increased his cotton cultivations. The cotton acreage in Uganda in 1916, 1926 and 1936 was 133,000 acres, 533,000 acres and 1,500,000 acres. The size of the individual plots increased and in some districts large communal plots were cleared every year with no intervening strips of bush or grass vegetation."

The general problem is well illustrated by conditions in the gently undulating and densely populated Teso district of the Lake Kioga basin which has suffered badly from erosion. The annual rainfall is 40-50 inches, the natives are essentially agriculturalists, but also keep large herds of cattle which are regarded as the insignia of wealth. The factors contributing to erosion, and their growth during 25 years, are enumerated by Martin in the following table.

Erosion Factor	1911	1921	1931	1936
1. Native population	?	266,396	270,211	302,000
2. Cattle	133,853	172,307	337,485	385,882
2. Sheep	38,746	25,308	50,625	47,632
2. Goats	93,413	91,526	119,346	146,525
3. Cotton (acres)	30,674	47,000	115,600	158,900
4. Ploughs	12	300	7,849	15,388

The demands of an increasing population necessitate either an increase in the cultivated area, with the consequent spread of erosion, the wholesale (and impracticable) removal of people from densely to lightly populated regions to ensure adequate resting periods for the land, or an increase in the productivity of the area already cultivated. Experiments are being made with planted grass covers and green manures to ascertain how far the necessary resting period can be shortened and the general fertility level raised. Farmyard manure is also being tested as an alternative or a supplement to green manures.

The increasing cattle population, which has resulted in widespread overstocking by pastoral tribes, likewise demands a larger grazing area, and has intensified the native practice of burning the grass and bush country in the dry season to stimulate the succulent young grass that comes up after burning. The common African difficulty is encountered here that the native is as unwilling to part with his animals as the white man with his money, and attempts are being made to substitute cash for cattle, and at the same time to encourage a taste for meat as it has been found (1) that the standard of native health improves on an increased protein diet. The firing difficulty is being mitigated by encouraging early strip burning, as the burnt strips act as fire breaks and allow the land to derive the undoubted benefits such as pest destruction that accrue from firing.

Mr. R. N. Fiennes, of the Veterinary Department, informs us that the preservation of grazing land in the tall grass-short tree savanna country depends largely on the annual grass fire, since if this fails, the country very quickly goes over to forest. The natives never clear the land except for purposes of cultivation, though they will cut branches for firewood without, however, killing the tree. Cattle in this type of country are never the primary cause of erosion, since if there is overstocking the grass is eaten short, the annual fire fails, and forest supervenes.

Expansion of cash and export crops like cotton has been inevitable to provide money for the country's development, but sloping cotton fields

are very liable to erode. Grass-covered contour bunds, built on every second foot of contour, are now used or recommended for native cultivation, together with closer spacing, as this provides a better cover for the soil, saves land area and increases yields. For the Teso district the best spacing is 3-5 square feet per plant, compared with the present average spacing of 9 square feet.

The effect on erosion of introducing the plough must have been considerable. In the Teso area, the light, short-grass bush soils are ideal for ploughing, which has now very largely superseded hand hoeing. A completely eroded, and now abandoned, ploughed field on the Serere experimental farm bears witness to the effect of moderately good European ploughing in ten years; native ploughing is worse, and is often performed up and down slopes. Systematic experiments are being made to ascertain the actual effect on erosion of ploughing as compared with hand cultivation.

One serious result of ploughing has been the spread of clean clearing with the complete removal of bush roots and stumps. Clean-cleared land suffers badly from desiccation in the dry season, and much benefit would be derived from suitably situated windbreaks. Indeed, a general reforestation scheme has been suggested, as the irregularity and torrential nature of the rainfall are powerful eroding factors and are believed to have been intensified by deforestation. Protection forests are also required to regulate stream-flow as well as for their direct influence in checking erosion. Notwithstanding the relatively high rainfall, five-sevenths of Uganda suffers from an insufficient water supply and there is reason to believe that as a result of erosion and other causes the general groundwater level is falling and the lakes are receding (3). Water conservation and soil conservation are two very closely related matters in Uganda. Destructive deforestation has been caused in many parts by nomadic pastoral tribes which have subsequently overstocked the cleared areas with huge herds of cattle. A major difficulty in carrying out a reforestation programme is to dispose of the pastoralists and their herds, but there is an urgent need to make a beginning. Particularly urgent is the reforestation of the important and now badly eroded watershed in Karamoja, a district acting as a buffer between the desert regions in the north (Turkana) and the densely populated agricultural regions to the south and west. A noticeable desiccation of Karamoja has already occurred since its denudation. In several parts of the Protectorate the problem exists in an acute form of how to co-ordinate tsetse-fly control (which necessitates clearing the bush) with soil conservation measures.

The deep and rich elephant-grass soils between Ruwenzori and Elgon, now largely used for cotton, coffee and food crops, resist erosion for a few years after first being cultivated, but later suffer badly. Erosion, however, can be satisfactorily and economically checked by artificial mulching and by leaving wide contoured strips of elephant grass between cultivated plots. In the densely populated Kigezi Highlands, having a well distributed rain-

fall of 30-40 inches, the natives have themselves adopted strip cropping across slopes, occasionally supplemented by rough terracing, on cultivated land, and have thereby prevented erosion from becoming a serious problem.

References (Uganda)

1. Courcy-Ireland, M. G. de, Hosking, H. R. and Loewenthal, L. J. A. An investigation into health and agriculture in Teso, Uganda. *Agric. Survey Committee, Nutrition Rept.* No. 1.—Teso, pp. 28. 1937.
2. Martin, W. S. *et al.* Agriculture and agricultural research in Uganda. (In the press).
3. Wayland, E. J. and Brasnett, N. V. Interim Report on soil erosion and water supplies in Uganda, pp. 121 and 3 appendices. 1936.

NYASALAND

Historical

According to Hornby (4), the inhabitants of the country about one hundred years ago lived almost entirely on the alluvial valleys and plains bordering on the numerous rivers and lakes. The alluvial plains at that time were very fertile, and the hills and mountain ranges beyond were covered with trees and vegetation capable of absorbing most of the heavy rains during the rainy season. The vegetation as a whole seems to have been comparatively unharmed by the annual fires which burnt around the fringes of the many forests.

The damage caused by unsettlement, destruction of forest by fires and unregulated felling and inferior methods of agriculture has been both rapid and intense. The vegetation is considerably altered in character by the fires which rage over the deforested hillsides at the end of the dry season, which may now last for seven months without rain. Records of the early missionaries and explorers confirm these statements and show that many streams then perennial are now only intermittent or do not flow at all.

The real indigenous inhabitants of the country (of Mang'anja stock) are not to be blamed for moving from one place to another; it is the more recent inhabitants, the Anguru, and the descendants of the invading Angoni, of Zulu origin, who practised shifting cultivation, with consequent denudation of hillsides, who present the greatest problem to the administration of Nyasaland as regards future food production.

Hornby surmises that "it will not be many years before the limit of possible food production will be reached." Important waterways such as the Shirê have silted up and much valuable alluvial soil has been washed away. Mountains and hills stand out as large masses of bare rock, treeless plains now extend over large areas, and sections burn fiercely every year.

Vegetation

The bulk of the natural vegetation is savanna, varying from woodland which is nearly closed forest to open parkland and orchard country.

Closed forest proper is limited in extent, evergreen types demand either high, well-distributed rainfall or adequate soil moisture, while closed deciduous bush has mostly been destroyed for agricultural purposes (6). Closed forests are little harmed by annual bush fires, but the other types of vegetation are harmed in varying degree, depending upon the height of the grass cover.

Soils

Hornby (2 and 3) has computed that much of the highland areas are losing soil at the rate of a quarter-inch per annum. The humus layer is never deep, except in the very small areas of closed forest, and is usually underlaid by a red subsoil which is readily converted into an almost impervious layer. Thus the danger of low absorption of the widespread savanna and open woodland soils at the end of the long dry season is obvious.

Over the greater part of Nyasaland are found crystalline rocks which consist essentially of variable gneisses and schists. Granites and syenites are also included in mountain areas, together with dolerite. These have given rise to a comparatively small number of soil series, the climatic soil type being well exemplified in the country. The effects of gully and sheet erosion soon appear after unregulated clearing on the ferruginous red loams of Nyasaland, in which a crust or layer of concretions containing iron and aluminium compounds is formed a few feet below the surface. The soils of Nyasaland in general, however, do not consist of types which are naturally very susceptible to erosion; many soils of the red loam, immature red loam and lateritic red loam groups can be described as subject to little abnormal erosion, while the position, slope and vegetative cover on the subtropical black earths and tropical chernozems reduce their erodibility.

Population Density and Movements

The high density of population is an important factor, particularly as development in central areas has led to congestion in the highlands, and steep slopes are being cultivated everywhere.

The figure of 300 persons per square mile is given as the limit that the average soil will support. When it is considered that the density is 77 per sq. mile in the Southern Province, where one-quarter of the land is infertile, and 34 per sq. mile in the Northern Province, where one-sixth of the land is infertile, " it is apparent that no time should be lost in determining a policy of soil conservation " (4).

Details of population movements or shifting cultivation can be found in (4), in the Survey of Central Nyasaland, 1933, and also Nyasaland Census Reports, 1926 and 1931.

Anguru natives in Nyasaland

1921	1926	1931
120,776	176,505	235,616

This increase is due almost entirely to immigration from Portuguese East Africa even into districts where population density varies from 88 to 116 per square mile.

Nearly all tribes except the Nyanja divisions have been invaders at one time or another, the Yao from 1860 onwards, the Angoni after the crossing of the Zambezi in 1835, etc.

Agricultural Methods

An important cause of the destruction of the vegetal cover in Nyasaland has been the past and present methods of most natives, the recent immigrants being most to blame. The combination of fire and the clearing of fresh land has led to excessive deforestation ; cultivation of all but the best soils is of a temporary nature ; in certain districts the methods of growing finger millet (*Eleusine coracana*) make extravagant demands on the land. Three methods, referred to as good, medium and bad, are described by Hornby (4) ; the most up-to-date method consists in manuring comparatively poor soils with materials such as Indore compost and cotton seed meal, with the introduction of legumes such as soybean, sunn-hemp and pigeon pea into a rotation.

It is considered that the use of ploughs and other implements in native agriculture in most highland areas would lead to disastrous results, and cannot be recommended as of first importance in the development of cultivation methods. There is little room for the necessary oxen, as nearly ten acres per annum are required for an ox in the highlands, while most lowland areas are unsuitable on account of tsetse fly.

It is suggested that the fertility of the land may be restored by allowing areas to revert temporarily to scrub and grass, although the practice of growing legumes in a rotation is to be preferred. The system of terracing advocated introduces large ridges with a base of a few feet which follow the contour at a grade of one in 400, and are spaced on an average forty yards apart, this distance being extended on lands of gentle slope. This ridge-terracing reduces erosion to a very low point if adopted early in the history of a field.

Ridge terracing has been carried out over large areas. Since 1930, supervisors of the Native Tobacco Board have been encouraged to terrace nearly every tobacco garden. Large funds have been provided by the Board for ridge terracing and tree planting.

Forest and Agricultural Policy

Notes on three lectures by Topham (6) give a general account of forest conditions and policy in Nyasaland, where forests and vegetative cover protect and conserve both soil and moisture.

Afforestation by planting is not a major part of departmental policy (6) ; protective forestry is the most important problem. The work of forming forest reserves was accelerated about thirteen years ago, particularly on most of the important catchment areas at the sources

of the main streams; the total area reserved now exceeds 2,600 square miles; on these areas a forest or administrative officer may prohibit native cultivation on hill slopes, a power which will probably be exercised to a greater extent in the future. Fire protective measures extend to complete protection only in a few small reserves, mainly consisting of plantations and coniferous forest. In all but one of the large reserves the grass is burnt early to reduce the intensity of the fires; the results are satisfactory where the grass is about three to four feet high. Where the grass is dense, and 6 to 8 feet high, early burning is generally so fierce as to set back the recovery of forest. Complete protection even for a single year may enable the regrowth of *Combretum* and *Acacia* to become established and to withstand controlled fires in subsequent years. The greater part of the forest reserves has short grass.

The most urgent forest problems requiring study are (a) management of indigenous village forest areas, and (b) improvement of technique for production of box wood and building timber. On the protective side forestry problems overlap agricultural problems; the proper utilization of each type of land must be determined. This is generally easy, but difficult examples are those of fertile land situated on slopes where there is danger of erosion. "The whole keynote of forest policy is the establishment of forestry practice and the inculcation of forestry ideas in every corner of the Territory."

Townsend (6) describes a Village Forest Area scheme, the object of which is to provide each village with an area of woodland from which the natives could obtain a sustained yield of poles and firewood. No definite conclusion can yet be made regarding the future of this scheme, but the indications are that the maintenance of such communal woodlands will become a firmly established practice as the headmen perceive its value and the beneficial results that can be obtained with small expenditure of labour.

There would appear to be differences of opinion regarding the advisability of permitting bush fires in the Forest Reserves, as described above, or as to the efficacy of the rules preventing natives from cultivating important stream sides or crests of hills and steep slopes from which important watersheds start. Hornby pleads for special attention to problems of soil erosion, even to the extent, if necessary, of the appointment of an officer with special powers.

It cannot be said that efforts to increase the production of one economic crop, cotton, in the lowlands have been successful in greatly improving the lot of the native in such matters as better food and health, clothing and housing and better agriculture all round (the cotton crop of Nyasaland in 1936 was only one-third of the estimate and 1937 has been distinctly disappointing). According to Hornby (1), it may be asked whether these attempts at increased cotton production might not be abandoned for other methods, in view of the innate conservatism and laziness of the natives, the ill-health generally and the curious system of

land tenure. Until 1932, there were only two officers stationed in definite districts for extension work, but they carried out no conservation work; one of these officers did some work of this nature late in 1935. The principles of extension work among native cultivators in Nyasaland require serious consideration.

Legislation and Administrative Measures

The legislation in force in Nyasaland is embodied in the Forest Laws and Rules, and there is usually a clause in the lease when land is taken up by European farmers for the replanting of a certain proportion with exotic or native trees. Unfortunately, much of this legislation has been of little value.

The Committee of the Board of Agriculture which met in January and February, 1933, to consider native agricultural methods, deforestation, bush-burning, overgrazing, settlement of immigrant natives, etc., made various recommendations, along the following lines.

Destruction of natural vegetation and cultivation of steep slopes should be prohibited under the power of Forest Rule 5 (2) (Gazette Notice No. 12, 1932) which reads :

"Any Forest Officer or Administrative Officer may at his discretion prohibit the felling, cutting and removal of forest produce on the tops and slopes of hills and mountains." Slopes with a gradient of more than one in eight should be terraced or used for certain crops; steep slopes to be used for the village forest scheme. Enquiries should be made as to the extent and methods of finger millet cultivation. Some check on the settlement of immigrant natives is required. Government might be asked to consider acceleration and extension of well-boring schemes in congested areas. District Fire Boards should be appointed to decide on limiting dates for controlled early-burning of vegetation.

According to Circular No. 3 of 1936 (5) the following measures are required for the improvement of agriculture and for control in the use of the land :

(A) Improvement of agriculture.

(1) Soil conservation; by terracing, draining, contour planting and contour bunding.

(2) Maintenance of soil fertility; by the use of cattle manure, compost, mulching and systems of rotations.

(B) Control in the use of the land.

(1) Protection of major catchment areas and watersheds by means of forest reserves.

(2) Protection of stream banks and steep hill slopes under powers of the forest laws.

(3) Preservation of natural vegetation on the poorer soils of the country.

(4) Preservation of belts of forest and natural vegetation on the better lands, to form windbreaks.

(5) Maintenance of village forest areas which should normally occupy land unsuitable for (or least suited to) agriculture, for example, hill slopes and poorer soils.

(C) Measures complementary to A and B.

(1) Prevention of settlement by immigrants.
(2) The redistribution of population where necessary.
(3) The opening up of unused land by well-boring and control of tsetse fly.
(4) The control of bush fires and insistence on the policy of early burning.
(5) The gradual suppression of finger millet cultivation by methods involving the burning of wood to heat the soil.

(D) The enactment of such legislation as may be necessary to implement the above recommendations, namely:

A. 1 and 2.
B. 3 and 4.
C. 1, 2 and 5.

References (Nyasaland)

1. Aberystwyth, Imperial Bureau of Pastures and Forage Crops. [Letter from] A. J. W. Hornby. Dec. 16th, 1936. Questionnaire on soil erosion in Nyasaland. [Typescript.] pp. 3.
2. Nyasaland Protectorate, Department of Agriculture. Bull. No. 1 of 1924. The destruction of vegetation and its relation to climate, water supply, and soil fertility. Pt. 3. The erosion of arable soil in Nyasaland and methods of prevention. By A. J. W. Hornby. Zomba, 1923. pp. 16.
3. ——————————————— Bull. No. 3. Studies of three important soil series of Nyasaland. By A. J. W. Hornby, Zomba, 1930.
4. ——————————————— Bull. No. 11. (N.S.). Denudation and soil erosion in Nyasaland. By A. J. W. Hornby. Zomba, 1934. pp. 32.
5. Nyasaland Protectorate, Government of. Circular No. 3 of 1936. Land control and development. [Issued from] The Secretariat. Zomba, 1936. 22nd Feb. pp. 4.
6. Oxford, University of, Imperial Forestry Institute. Institute Paper No. 5. Forestry and soil conservation in Nyasaland. By P. Topham and R. G. R. Townsend. Oxford, 1937. pp. 20.

BRITISH SOMALILAND.

Somaliland is primarily a pastoral country, but in the western areas farming operations are carried on. In other parts of the country the water of the ephemeral rivers is used; these rivers usually contain from 5 to 10 per cent of alluvium, and enable small native irrigation schemes to be operated in a few places (1 and 2).

In small areas, particularly in Borama, farm erosion is a very grave menace. Only the simplest methods of control can be used in a primitive and somewhat self-opinionated community, but such methods as ploughing across the slope, ploughing a transverse ridge at intervals, and leaving a narrow grass strip between areas on hillsides have been recommended. The cultivation of beans among the jowari is also recommended, as this not only tends to prevent erosion, but also provides substantial dry season grazing and benefits the soil. The Government is prepared to buy large

quantities of beans and peas in 1938, thereby stimulating agriculture, improving soil, controlling erosion and improving the diet of the people.

Under the present system every farmer is supposed to cultivate the whole of his land every year and it is only by breaking this regulation that the land can be rested. The lack of markets makes the growing of a variety of crops uneconomical. Practically the only crop grown is jowari ; small amounts of crops such as gram, barley and maize are seeded on a very limited scale. The one-crop system not only lowers the vitality of the soil, but also exposes the plants to increasing parasitism. As the farmer is unable to own his own farm, he has no incentive to develop his land. Once he understands the value of manure, it will not be difficult for him to gather the jowari stalks and feed them in the field under his own supervision. He will also appreciate the value of carrying the homestead manure to the field. To encourage the cultivation of a diversity of crops, it was decided to purchase the gram crop for the use of Government animals ; this has resulted in a considerable increase in the cultivation of this beneficial plant.

Much of the pasture and browsing of the country is degenerating. This does not appear to be due so much to lack of rainfall as to failure to use rain. The main causes for the degeneration of pastures in the past are the wholesale destruction of grass and trees during the Mullah campaigns, and the throwing open of the whole country to indiscriminate grazing. Factors operating at the present day to continue this destruction are the Somali habits of following the rainfall and of allowing their stock to graze the newly sprouting grass. A few graziers may remain in a district after the major part of the tribe has moved on, and do immense damage to the grazing with a flock of perhaps a hundred sheep as they travel in line abreast, not eating the thicker grass but going to those patches of ground which are bare of vegetation and eating off any young grass. This destruction of grass leads to the further destruction of vegetation by sheet erosion, wind and water, and nullah formation. The rainfall is lost rapidly as the water flows away in the nullahs or seeks its own level and evaporates rapidly, leaving large areas exposed to drought.

Trees which were formerly abundant are now killed by the drought which follows the destruction of the grass. The reduced amount of water available for the trees and bushes exposes them to serious attack by ants and insect borers common in dry areas. A factor which is not usually considered in the calculation of humidity is the loss of dew resulting from the destruction of bush ; dews are very heavy in parts of the country.

Other contributory factors to soil erosion which are perhaps not so important to-day as in the past, are :

(1) The burning of grass, which is done to destroy the ligneous dhurr grass (*Andropogon crytocladus* Stapf) and to enable the new green shoots to be available for stock.

(2) The accidental destruction of vegetation resulting from the felling of trees by burning.

(3) The lighting of fires in karias (moveable native homesteads) among thick grass.

A smaller but not less effective destruction is caused by the perhaps unavoidable practice of placing ditches beside the dirt-roads. These ditches soon become deep nullahs and deprive plains of the water which they would normally receive as run-off from the low hills surrounding them.

In former times when the Somali tribes were in active enmity with one another every tribe had its own grazing and guarded its jilal (dry season) grazing at the point of the spear, no members of the tribe being allowed to remain behind when the main body of the tribe had moved. The abolition of this custom of reserving jilal grazing is the fundamental cause of the vicious circle of circumstances which is causing such serious loss to the country's grazing and resulting in all forms of erosion on a wide scale.

To remedy matters a return to the former native practice of deferred grazing will undoubtedly do much. An illustration of the effect of deferred grazing is the common observation that where stock cannot eat the grass for a few months it grows rapidly if seed can become established. The Somali grasses are well adapted to the scanty rainfall.

In 1935, thanks to the co-operation of the District Officer, Burao, sanction was obtained and a plan carried through to close part of the Ain valley and the Tifafli and Oedegeyeh valleys; the effects of this deferred grazing were striking.

The natives certainly understand the cause of the degeneration of their pastures, and many know that deferred grazing is the solution, without any advice having been given on the matter. The initiation and execution of a plan, however, are complicated by the fact that most tribes have increased in numbers to such an extent that their former grazing is now inadequate, and general grazing conditions have deteriorated to such an extent that the pastures cannot now accommodate their stock. The initiation of a plan is a political, agricultural problem.

An Ordinance (No. 22 of 1936) entitled "The preservation of grazing areas and water ordinance" was enacted by the Governor of the Somaliland Protectorate at Sheikh on December 19, 1936. The District Officer or Assistant District Officer in charge of any district may, in consultation with the Veterinary and Agricultural Officer and with the approval of the Governor, prescribe in his district any area in which it is deemed desirable, for the purpose of preserving grazing, that grazing shall be temporarily prohibited, and in such case shall issue such orders as he may consider necessary to prevent grazing in such areas. Provided that where the enclosing of any such area prevents access to a well the water from such well shall be made available for persons and animals outside such enclosed area by a channel or pipe from such well or by such other means as may be deemed adequate. It shall be lawful for a District Officer or Assistant District Officer to permit any animal to be taken in transit through a prescribed area without undue delay.

When such an area has been prescribed any stock found therein may be

impounded until the owner pays a fine in respect of the animal and the expenses of the impounding. If this is not done within 28 days the animals shall be liable to forfeiture.

Large tracts of country have been closed and much larger areas are likely to be placed under deferred grazing in 1938. The benefits derived from, and ease of accomplishing this closure have far surpassed the expectations.

A full-time Agricultural Officer has been appointed to deal primarily with grazing problems. One of his first duties will be the introduction of a permanent system of deferred grazing for the whole country.

References (British Somaliland)

1. Aberystwyth, Imperial Bureau of Pastures and Forage Crops. Correspondence on soil erosion in Somaliland, from E. F. Peck. Burao, 18 December, 1936. pp. 2. With accompanying memorandum [Typescript] pp. 6, extracted from British Somaliland, Dept. Agric., Ann. Rep. for 1935.
2. ——————————————— Correspondence on soil erosion in Somaliland, from E. F. Peck. Burao, 9 November, 1937. pp. 4.

West Africa

NIGERIA

Mr. H. C. Doyne, senior chemist to the Agricultural Department, has supplied us with the following note.

" Soil erosion has become a serious menace in the South-Eastern Provinces of Nigeria. In this area the population is dense, intense shifting cultivation in the past has caused much of the land to be denuded of high forest, and the recuperative period has been shortened drastically so that vegetative degradation has set in. In the more hilly areas gullies of 100 feet deep caused by erosion are not exceptional and the soil which is derived principally from sedimentary deposits of the Eocene and Tertiary periods is becoming an intensely acid, allitic sand. The rainfall of this area is approximately between 70 and 150 inches per annum, increasing in a southerly direction towards the coast.

" In the South-Western Provinces the rainfall is considerably less (50-70 inches per annum) and as the population is not so dense, the land gets rapidly covered with vegetation and erosion is not particularly serious except in the more highly farmed areas. The soil in this area is derived mostly from pre-Cambrian gneiss and is largely of the Ilepa type. Erosion, when it does occur, causes the removal of the top soil and the exposure of the underlying concretionary conglomerate or the mottled Ilepa clay (the latter, on exposure and desiccation, tends to form concretions).

" In Northern Nigeria, sheet and to some extent gully erosion are more evident than in the south-west. In spite of the fact that the annual rainfall is lower than other parts of Nigeria (25-45 inches) and the population is less, considerable erosion is caused by the early rains. An intensely dry season prevails from November to March which causes much of the grass vegetation to dry out completely and, owing to this lack of vegetational cover, the rain (which is intense, as in other parts of Nigeria) causes considerable loss of soil through excessive run-off. Rivers which are completely waterless during the dry season become raging torrents in the rains. During the rainless periods, an extremely dry wind (the Harmattan) blows from the north. This causes a certain amount of aeolian erosion and during a quiescent period, immediately after a high wind, a pall of dust covers the whole area. The soil is a modified form of that derived from the pre-Cambrian gneisses in the south, but is much intermingled and covered with a (probably) wind-borne drift containing a high proportion of fine sand. This drift soil increases in depth as the northern boundary is approached."

Doyne points out that erosion is more evident on plastic, siallitic soils than on allitic soils. As a result, the former tend to occur in alluvial

deposits, the latter on slopes and high ground. He suggests, therefore, that the formation of surface lateritic deposits may be due, at least in part, to the action of erosion as well as to the downward leaching of silicates.

A question of considerable interest—though perhaps its urgency has been over-emphasized—to Northern Nigeria is the extent to which the Sahara Desert is encroaching as a result of soil deterioration and wind erosion. Stebbing (3) holds the view that on a wide belt on the southern fringe of the Sahara, the present so-called savanna forest is a relict of former deciduous high forest, and is itself deteriorating, under the influence of increasing population, overgrazing, burning and cultivation, into completely open land exposed to the full force of northerly winds and sand drift. Stebbing adduces evidence of abandoned villages now lying in sandy wastes and the observations of French and British administrative officers to show that the desert has progressed southward during the last three centuries at an average rate of about a kilometre a year. The matter, however, demands further study before the progress of the Sahara can be definitely determined, but the deterioration of the savanna country appears to be well established. In Northern Nigeria, an economic cause of the deterioration has been the great population movements from the French Niger Colony owing to recent well boring and tax reductions in Nigeria (1). It has not yet been proved that forest destruction has been accompanied by a climatic change towards desert conditions.

The economic effects of erosion have not yet been very serious (4), but the authorities are fully alive to the need for controlling it. In general, the farms are small, and cultivation on mounds is a common practice. In some districts this native anti-erosion measure has been improved by substituting contour ridges for the mounds. Very deep ridging is practised, the ridges usually being 6 feet from crest to crest and 2½ feet from crest to furrow. The Agricultural Department aims at changing the existing shifting cultivation, which has broken down under modern conditions, by introducing mixed farming in Northern, and cover crops in Southern Nigeria, so that more continuous cultivation can be carried on without loss of fertility. In the North, large increases in yields have been obtained from dressings of farmyard manure as low as 2 tons per acre (2). Promising results have been obtained with *Mucuna utilis* and *Phaseolus lunatus* in the south-western, and *Calopogonium mucunoides* and *Tephrosia candida* in the south-eastern areas.

The Forestry Department has carried out operations on the badly gullied Udi plateau in the Onotsha Province (Southern Nigeria) by ridge and ditch methods (1). Grazing was prohibited in the area, which was then ditched along contours by six-foot-long ditches arranged in "echelon" fashion so that the water passing between ditches on one contour was caught in a ditch below. The ridges were seeded and the intervening ground reforested. At the same time small earth dams were built at the heads of the gullies, and the tops of the dams and the sides

of the gullies were planted with grass. These measures, combined with protection from fire, grazing and cultivation, promise to control erosion effectively. In the extreme north, the Forestry Department is experimenting with strip planatations to check wind erosion, but has encountered difficulties both from the severity of the climate, and the impossibility of fully controlling grazing, fire, etc. (1). The Dum Palm (*Hyphaene thebacia* Mart.), however, has been successfully established along the international boundary, and beneath it a complete cover of natural vegetation has sprung up.

References (Nigeria)

1. Grasovsky, A. Anti-erosion and anti-dessication operations in Nigeria. *Imp. For. Inst., Oxford.* pp. 9. 1937.
2. Hartley, K. T., and Greenwood, M. The effect of small applications of farmyard manure on the yields of cereals in Nigeria. *Emp. J. Expt. Agric.* **1.** 113-21. 1933.
3. Stebbing, E. P. The encroaching Sahara: the threat to the West African colonies. *Geog. J.* **85.** 506-524. 1935.
4. Stockdale, F. A. Soil erosion. *Emp. Cott. Gr. Rev.* **12.** 1-8. 1935.

GOLD COAST AND SIERRA LEONE

The Acting Director of Agriculture for the Gold Coast, in a letter dated January 4, 1938, states that "erosion cannot be considered as a serious problem in the Gold Coast at present, and no legislative measures directed towards this specific end are either in force or proposed. Isolated cases can be seen in many areas, where erosion has taken place through the denudation of steep slopes for food-farms, or through anti-tsetse clearings at river crossings, but the damage is not extensive and the protective cover is soon replaced if the area is abandoned. . . . . .

"An area which is engaging attention is the extreme north-east strip of the Northern Territories. This district is heavily populated, but the people are unwilling to move to unoccupied land in the near vicinity. They live in scattered compounds which are so close that nearly all the land between them is farmed annually without rest. The cropping is almost purely cereals (millet and guinea corn) planted on the flat. Cattle and goats graze off the leaves in the stubble and the stems are used for fire-wood. The land is consequently bare at the time of the first rains after the dry season, and though planting takes place immediately with the rains, without previous cultivation, a certain amount of sheet erosion is inevitable. The people are being encouraged to adopt ridging and to cultivate, to leave protective strips of grass and bush, and to refrain from burning off the vegetation on those areas which are not farmed, cutting the grasses either as fodder or bedding for their cattle. The people are very primitive and slow to adopt changes, but there are prospects that they will appreciate the beneficial effects of the remedial measures recommended."

Published information on erosion in these territories is very scanty. Stockdale has summarized the present position as follows.

" The general position in the Gold Coast is not as satisfactory as that in Nigeria. Vast areas of high rain-forest have been cleared for food farms and for cacao cultivation. It is estimated that there are over a million acres under cacao, and although no special measures have been taken to prevent erosion, the losses have not been so great as might have been expected, owing to the stumps of forest trees having been left in the clearings, and to the establishment of the cacao in a mixed plant-cover of food crops. Many of these crops are grown on mounds, and where this system of cultivation is practised the soil losses from erosion are not excessive. There have been, however, considerable areas of forest cleared for cultivating maize, which is the staple food crop in the Gold Coast. In many of these areas erosion has developed and it is now common to see large areas of land devoid of its surface-layer. This is particularly noticeable in the coastal areas where the population is dense and a fair amount of erosion is also noticeable in areas where the population has increased considerably during the past twenty years.

" In the Northern Territories of the Gold Coast stock numbers have been increasing since rinderpest has been controlled. The Department of Animal Health is endeavouring to demonstrate the value of cassava roots and hay as food for cattle during the dry season, whilst the Department of Agriculture is testing the practicability of introducing a system of mixed farming in those areas where the population is fairly dense. Under the existing system much of the land is being degraded and a certain measure of erosion is to be noticed.

" In Sierra Leone, soil erosion has been responsible for serious loss of fertile top soils from the hills of the Colony behind Freetown. Many coffee and other cultivations have seriously deteriorated because no attempts have been made to terrace the land with a view to preventing soil wash under the heavy rainfall of the area. Attempts are shortly to be made to resuscitate some of these cultivations and to encourage the establishment of terraces and other measures designed to check erosion.

" In the Protectorate the position is not so serious, for here the chief agricultural problem on the high lands is the maintenance of soil fertility. Shifting cultivation is generally practised for the production of hill rice, millets, and other food crops, and land which was formerly under good forest is now covered only with bush-growth, and in many areas with a poor cover of grass. There is naturally a certain measure of soil washed into the swampy valleys which intersect the undulating hills, but increasing attention is now being given to the cultivation of rice in these swamps and it is expected that the pressure on the high lands will thereby be reduced."

Reference (Gold Coast and Sierra Leone)

STOCKDALE, F. A., Soil erosion in the colonial empire. *Empire J. Expt. Agric.* **5.** 281-97. 1937.

United States of America

Introduction

The literature on erosion in the United States is already so vast that any summary of it within the scope of this Bulletin must be very sketchy and incomplete. The United States is the only country where even an approximate estimate of erosion damage has been made. It is also the most advanced in viewing erosion in its proper relation to national life : the Report of the National Resources Board (74) issued in 1934 is a document worthy of the most careful study as a statement of a plan of national conservation in its widest sense and centred on the conservation of eroding soil. Erosion has ceased to be the concern merely of the direct users and occupiers of land ; its impact on industry, national health, politics, etc. is clearly recognized, and its control is regarded as a matter for the whole nation, acting in co-operation. Co-operation is, indeed, the keynote of the erosion, or—to use a more comprehensive word—the conservation policy of the United States.

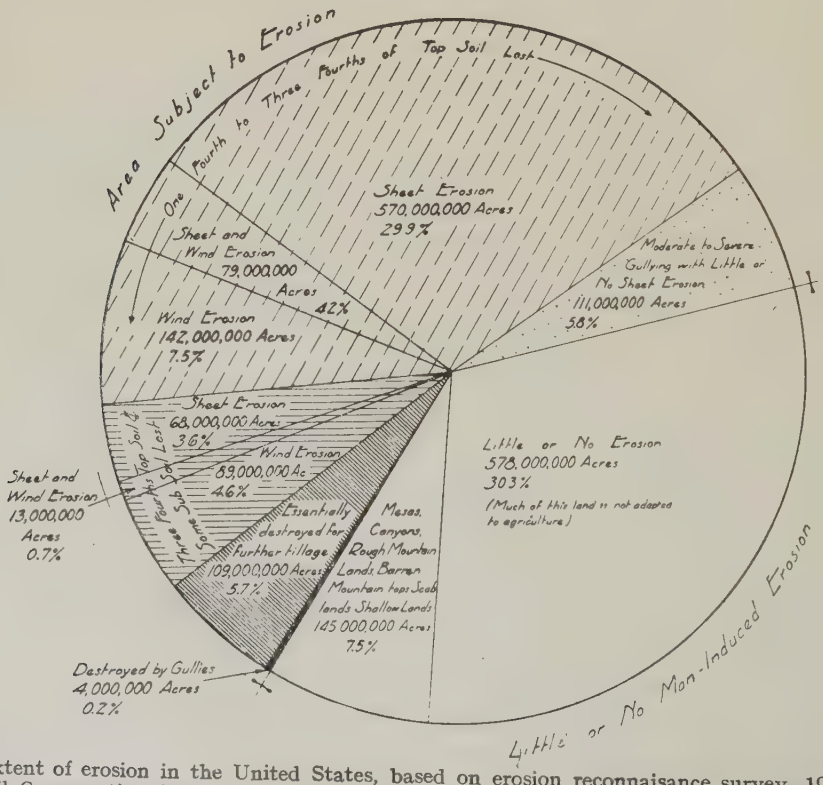
The idea of conservation, to save America from the consequence of its rapid exploitation, is not new, but apart from spasmodic attempts by enlightened individuals, it was Theodore Roosevelt who first roused the people to its nation-wide importance. During his presidency attention was given mainly to plans for conserving mineral, forest and water resources. The high prices of the war and post-war period, however, encouraged waste on an unprecedented scale, and it needed the financial depression, and a series of droughts and spectacular dust storms to rouse the nation again to the much increased gravity of the situation. During Franklin Roosevelt's presidency, conservation has become a political and social question of the first importance. The focal point has now shifted to the soil, the loss of which by erosion and exhaustion is infinitely more serious and irreparable than the wastage of underground and overground wealth with which the former conservation movement was mainly concerned.

The earlier organizations, however, still exist, have sprung into greater activity than ever, and are reinforced by new organizations, such as the Farm Security Administration and the Soil Conservation Service, particularly the latter. Thus " conservation " in America now involves the preservation or rational utilization, with the needs of posterity in mind, of agricultural and pastoral land, of forests, of minerals and oil, of industrial products, of wild animals, of recreational resources (national parks), and finally of man himself. It is important to emphasize that as erosion affects and is affected by many other aspects of conservation, it is being treated more and more as an integral part of a much wider problem. If we confine ourselves here mainly to considering the agricultural and soil aspects of conservation, it is owing to limitations of space and to preserve some uniformity of treatment with other sections of the Bulletin. It has not

been possible to deal extensively with the activities of the Forest Service of the U.S. Department of Agriculture. For discussions of conservation and erosion in their wider aspects the reader is referred to the National Resources Board Report (74), " Our Natural Resources and their Conservation " (33), " Deserts on the March " (37), and numerous other books and official documents. The Yearbook of Agriculture of the U.S. Department of Agriculture for 1938 is to be devoted entirely to the soil work of the Department, including the research activities and the extension and administration programmes. This summary of the Department's work will give a clear indication of the relationship of the soil erosion control work to the other agricultural problems, both physical and social. It will contain a map of the United States showing the important soil regions.

Extent of erosion

A preliminary reconnaissance erosion survey of the United States was made by the Soil Conservation Service in 1934. The survey was made by counties, the county surveys were combined into State surveys, which were finally assembled and represented in the form of the diagram reproduced below (24).



Extent of erosion in the United States, based on erosion reconnaisance survey, 1934, by the Soil Conservation Service.

The area with little or no erosion covers 30 per cent of the total land area, and much of it is unsuitable for cultivation ; the rest of the diagram speaks for itself.

A generalized erosion map is reproduced on p. 124.

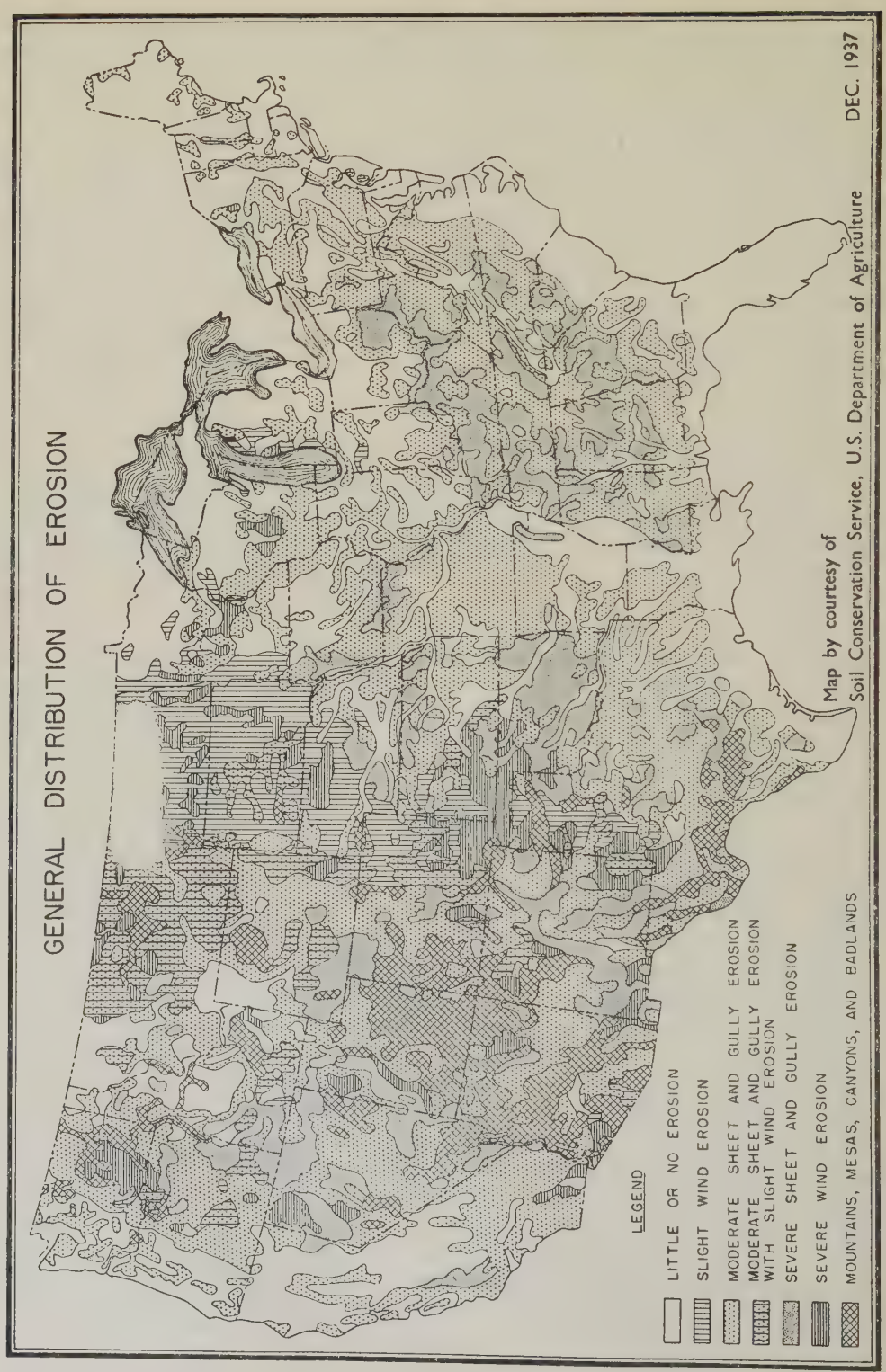
The distribution and severity of erosion are complex functions of environmental factors on the one hand and land-use practices on the other, and are, indeed, to a large extent measures of the maladjustment between them. The rapidity with which America was opened up resulted in land-use development being governed primarily by immediate economic considerations, and the problem to-day is to effect a lasting readjustment between land-use and the natural environment. For this reason the attack on the erosion problem has been organized regionally, and control measures are being planned for, and applied to, each complete geographical region as a whole.

Organizations concerned in agricultural conservation

Most of the research and general conservation operations dealing with soil and vegetation in the United States are under the control of the Department of Agriculture, which is subdivided into some twenty-five subdivisions (51) dealing with all the more important aspects of land utilization from the administrative, economic, practical and scientific points of view.

The chief subdivision within the Department concerned with the prevention and control of erosion on agricultural lands is the Soil Conservation Service. The functions of this Service involve research and investigation into the problems of soil erosion and its control and the propagation of erosion-control practices through the medium of practical demonstration. The Service maintains erosion-control experiment stations in the several major agricultural regions ; operates a network of demonstration areas extending into forty-three States ; maintains a series of nurseries for the production and propagation of erosion-control plants and carries out necessary survey work relating to the extent and nature of erosion, the effect of erosion on reservoir silting and similar related physical and economic problems.

In its task of administering the national forests the Forest Service plays an important part in the conservation of soil and vegetation. Its activities fall into three main categories : co-operation with States and private owners of forest and woodlands ; management of the national forests ; and research. In its co-operative relationship, the Forest Service distributes planting stock to farmers for windbreaks, shelterbelts, and farm woodlands, and aids in protecting the soil cover from fire. At present, about 176 million acres of land are in public ownership within the United States. These contain timber, forage, and water resources of great value besides supplying recreation and other public benefits. All forms of use are carefully regulated to conserve and to build up the natural resources. About half the area of the national forests, 83 million acres, is grazed.


GENERAL DISTRIBUTION OF EROSION
LEGEND
LITTLE OR NO EROSION
SLIGHT WIND EROSION
MODERATE SHEET AND GULLY EROSION
MODERATE SHEET AND GULLY EROSION WITH SLIGHT WIND EROSION
SEVERE SHEET AND GULLY EROSION
SEVERE WIND EROSION
MOUNTAINS, MESAS, CANYONS, AND BADLANDS
Map by courtesy of
Soil Conservation Service, U.S. Department of Agriculture
DEC. 1937

The research programme of the Forest Service is conducted largely at the national Forest Products Laboratory and at twelve forest experiment stations authorized in the McNary-McSweeney Forest Research Act of 1928. The research programme of the Forest Service covers all phases of forestry, all classes of land, and the entire United States. Integration in the stations of investigations in the different fields assures a co-ordinated attack on the important problems of each region.

The pasture aspects of erosion control are of great importance in both the eastern and western United States. The extensive pasture programme of the Division of Forage Crops and Diseases, Bureau of Plant Industry, is, therefore, closely connected with the general conservation work of the Department. The U.S. Regional Pasture Research Laboratory in Pennsylvania is formulating its research programme on a regional basis according to an outline approved by the Department and the Directors of the State agricultural experiment stations in the twelve north-eastern States ; this programme is being developed in co-operation with related research in agronomy, pasture management and grazing practices as conducted by the various State agricultural experiment stations throughout the region. The results obtained should be applicable to the problem of preventing erosion on the pastures of the eastern States and to the introduction of suitable hay and pasture crops into the rotations recommended for erosion-control practices.

Although the immediate problem of erosion calls for the widest possible effective use of available plants, it is recognized that through plant breeding, strains better suited to the requirements of erosion control may be provided. This applies to the production of herbage plants suitable for growing in the east, and also to the many-sided study of the grasses of the western States, which is being carried on by officers of the Division of Forage Crops and Diseases in a number of centres in the west, such as Manhattan (Kansas), Hays (Kansas), Lincoln (Nebraska), Logan (Utah), Mandan (North Dakota), Woodward (Oklahoma), Pullman (Washington), etc.

Other Bureaux and Services of the Department of Agriculture directly or indirectly concerned in various ways with conservation questions are the Bureaux of Chemistry and Soils, Animal Industry, Biological Survey, Agricultural Economics and the Extension Service.

Soil Conservation Service : Headquarters Organization

The Soil Conservation Service is the outgrowth of the Soil Erosion Service, an agency established in October, 1933, to carry out the provisions relating to the prevention of soil erosion of the National Industrial Recovery Act. In March, 1935, the Soil Erosion Service was transferred intact from the Department of the Interior to the Department of Agriculture. In the same month the Secretary of Agriculture directed the unification of all Department of Agriculture activities pertaining to soil erosion under the Soil Conservation Service (39). This order automati-

cally expanded the organization to include erosion-control experiment stations of the Bureau of Chemistry and Soils and the Bureau of Agricultural Engineering, the erosion nurseries of the Bureau of Plant Industry and the Emergency Conservation Work Camps previously assigned to the Forest Service for erosion control work on agricultural lands.

The Soil Conservation Service in Washington, D.C., is organized as follows :—

Division of Conservation Operations

Sections

Agronomy and range management
Conservation nurseries
Engineering
Erosion control practices
Wildlife management
Woodland management

Division of Co-operative Relations and Information

Sections

Co-operative planning
Co-operative relations in extension
Information

Division of Research

Sections

Soil and water conservation experiment stations
Watershed studies
Sedimentation studies
Climatic and physiographic investigations
Hill culture
Economics of soil conservation

Division of Watershed and Conservation Surveys

Sections

Cartography
Conservation surveys
Flood control surveys

Division of Conservation Operations

This Division directs and supervises the development and proper continuation of the various work operations and field projects. Plans and procedures are developed for the careful selection of demonstration areas on the basis of departmental policy and actual field conditions. The Division is also responsible for the organization of field forces to meet special or emergency situations, such as the disastrous floods which have occurred in the eastern United States in recent years. Plans are developed for co-operating with other agencies in the employment of distressed farmers on soil and water conservation projects in drought affected areas.

Erosion-control practices. In addition to furnishing field supervision and assistance to the men in the field responsible for farm planning, a special unit in the Washington office is responsible for reviewing the co-operative agreements, described below, to determine whether the agreements and plans adhere to national policy and conform to the project working plans. Co-ordination of control measures is one of the primary functions of the Section.

Agronomy. The agronomic operations of the SCS form an important part of a co-ordinated programme of erosion control on farm, fields and pastures. Close co-operation is maintained with agronomists of the State experiment stations and the Federal Extension Service, representatives of the Bureau of Plant Industry, the Forest Service, the Bureau of Animal Industry and other agencies of the Department of Agriculture.

Agronomic control of erosion involves the use of rotations and best farming methods ; strip cropping, contour farming and tilling methods ; the proper management of pastures, including controlled and rotational grazing, reduction in livestock, establishment of supplementary pastures, and the use of contour furrows and the reseeding of a large acreage of erodible land removed from cultivation.

Nurseries. The Section of Conservation Nurseries is primarily concerned with providing suitable planting materials for use in the various phases of conservation work and general revegetation. Its major work includes the production of nursery stock and the collection of mature seeds and plants in quantity, as well as technical supervision in obtaining commercial seeds, fertilizers, etc. Specialized activities of the section include (1) assembling and observing plants which may have greater value in erosion control than those now used ; (2) collecting small lots of seeds for inter-regional exchange and test ; (3) making seed-germination tests ; (4) working out appropriate practical methods of propagation ; and (5) developing special methods and machinery for harvesting native seeds.

Engineering. Mechanical measures are necessary in many instances to control run-off effectively and prevent destructive erosion so that protective vegetation may be established. The field work of the section consists of applying to local conditions such measures as terracing, contour furrowing, ridging and listing, and the construction of terrace outlets, gully-control structures, diversion ditches, water-conservation dams and of water-spreading dams and dikes in the semi-arid regions of the West.

Woodland management. The work of the Woodlands Section falls largely into three classes: (1) planting forest trees and shrubs for erosion control ; (2) woods management (including fire protection, stand improvement and management plans), and (3) co-operative development and management of community or association forests in agricultural communities. The chief activities fall within the first and second classes, and are specifically for erosion control.

Wildlife Management. No manipulation of the soil can be without an effect upon the creatures dependent upon the soil for existence. In 1935 a special section of the Service was organized, with the object of making the operations of the Service as beneficial to wildlife as is consistent with the control of erosion and the primary use of land.

Division of Research

A balanced programme of research is carried on co-operatively with State agricultural experiment stations, and in certain instances with other organizations and agencies, such as universities, research institutions, State water boards and the National Research Council. Plans and programmes are formulated in collaboration with the director of the State experiment station.

Erosion Experiment Stations. The work of each erosion experiment station or research project is under the immediate supervision of a local research superintendent, with suitable State and Federal specialists on various aspects of the local problems. Research and scientific investigations of the Service are supervised and directed by the Chief of the Division of Research or his representatives in co-operation with the directors of the State experiment stations concerned. These erosion experiment stations are situated in many different parts of the United States; their distribution is not on a regional basis, as has been adopted for the demonstrational project works of the Service, but is arranged on a representative selection of the problem areas in soil conservation research in the United States (72); these problem areas are differentiated on the basis of an environmental complex in accordance with existing conditions and future potentialities of erosion and moisture retention, including as principal features: present erosion, susceptibility to erosion, topography, climate, soil, natural vegetative cover and vegetative history during use of the land by man. Eighty-three such problem areas are recognized, on forty-one of which the conservation problem is regarded as serious, on twenty-six moderate, and on sixteen slight.

The Division of Research is organized with six closely co-ordinated subdivisions, concerned respectively with soil erosion and moisture conservation studies, watershed studies, sedimentation studies, climatic and physiographic studies, hill culture studies and economics of soil conservation. The scope of the research is more fully explained below.

Division of Watershed and Conservation Surveys

A survey of physical land factors is the basis for every erosion-control plan, whether it be a detailed plan for a farm or a more general programme for a larger area. Recently the Department of Agriculture has also begun preliminary examination of most of the major watersheds in the country with a view to formulation of recommendations for flood control.

Cartography. The Section of Cartography procures aerial photographs for field work, prepares suitable base maps, and transfers field survey data to the finished maps. Contracts were awarded in 1936 for enough aerial surveys to provide base maps for most of the conservation surveys that are now under way.

Conservation surveys. All planning is based upon a physical land inventory which depicts present land use, degree of erosion, slope, and type of soil. Detailed conservation surveys are conducted (1) on demonstration projects and other areas where erosion-control practices are to be planned on individual farms, and (2) on selected areas where information is desired or where future demonstrations or soil conservation districts may be located. Reconnaissance surveys furnish general information on selected areas, but are not adequate for planning on individual farms.

The Section includes a staff of inspectors who supervise and correlate field conservation surveys, and a report unit which analyses survey data and assists in preparation of reports for publication. A handbook of conservation survey procedure was issued in 1936.

Examples of reconnaissance surveys which may be mentioned include that undertaken in twenty counties in the Southern Great Plains, where wind erosion is severe (18), the survey of Puerto Rico (see under West Indies), the extension of the Southern Great Plains survey to cover 19,000 square miles in eastern New Mexico, a survey of 6,500 square miles in North Dakota, and of the Brazos River watershed, Texas (47).

Flood control surveys. The Omnibus Flood Control Act of 1936 authorized the Secretary of Agriculture to make preliminary examinations and surveys for "run-off and waterflow retardation and soil erosion prevention" on 222 watersheds. By subsequent amendments, this authority has been expanded to include practically the entire land area of the country. The Secretary has designated the Soil Conservation Service, Forest Service, and the Bureau of Agricultural Economics as the agencies to carry the primary responsibility for the flood control activities of the Department.

The Section of Flood Control Surveys represents the Soil Conservation Service in the flood control survey programme, working in close co-operation with representatives of the other two bureaux. The field work is conducted under the joint responsibility of committees composed of representatives of the three bureaux; the chairmanship of the committee being an employee of the Soil Conservation Service, where agricultural lands are primarily involved, and a representative of the Forest Service, where forest-lands predominate.

Soil Conservation Service: Regional Organization

During the period from July to September, 1935, the SCS effected a major re-organization of its field operating structure in order to accommodate a four-fold increase in the scope of field operations. In an effort

to decentralize administration and technical supervision, the field organization, previously operated on a project basis, was divided into eleven administrative regions, each of which conforms as closely as possible with regional problems of soil conservation and land use.

Region No.	Name of region	Headquarters	States included
1	Northeast	Williamsport, Pa.	West Virginia, Maryland, Pennsylvania, Rhode Island, Delaware, New York, Connecticut, Massachusetts, Vermont, New Hampshire, Maine, New Jersey.
2	Southeast	Spartanburg, S.C.	Virginia, North Carolina, South Carolina, Georgia, Alabama, Mississippi, Florida.
3	Ohio Valley	Dayton, Ohio	Ohio, Michigan, Indiana, Kentucky, Tennessee.
4	Midsouth	Fort Worth, Tex.	Arkansas, Louisiana, Texas (except Texas Panhandle, which is included in region No. 6).
5	Upper Mississippi	Des Moines, Iowa	Minnesota, Wisconsin, Illinois, Iowa, Missouri.
6	Southern Great Plains wind erosion	Amarillo, Tex.	Texas Panhandle, Oklahoma Panhandle, western Kansas, Colorado east of the Continental Divide, eastern New Mexico.
7	Central Great Plains	Salina, Kansas.	Nebraska, Kansas (except portion included in region No. 6), Oklahoma (except Oklahoma Panhandle included in region No. 6).
8	Southwest	Albuquerque, N. Mexico.	Arizona, Utah, Colorado west of the Continental Divide, western New Mexico.
9	Northwest	Rapid City, S. Dakota.	North Dakota, South Dakota, Wyoming, Montana.
10	Pacific Southwest	Santa Paula, Calif.	California and Nevada.
11	Pacific Northwest	Spokane, Wash.	Washington, Oregon, Idaho.

Regions of the Soil Conservation Service.

Each of the eleven regions is under the jurisdiction of a Regional Conservator with headquarters at a point most convenient from the standpoint of transportation, communication and accessibility to projects within the region. Operations and co-operative relations in each State within the region are under the supervision of a State co-ordinator with headquarters in most cases at, or near, the State College of Agriculture. The fullest possible co-operation with State agricultural agencies is maintained through State Advisory Committees composed of the State Co-ordinator of the SCS, the director of the agricultural experiment station, and the director of extension. Additional members may be appointed to this committee, but in no case does the membership exceed five.

Field operation projects and Emergency Conservation Work Camps are under the administrative supervision of the Regional Conservator through the State co-ordinator. Responsibility for general supervision of field activities rests with the State co-ordinator, who carries out the major operating policies established for the region as a whole. Each field project is under the direction of a project manager and a staff composed of specialists in each phase of agricultural work involved in the co-ordinated programme used by the Service in that locality. These specialists include soil scientists, engineers, agronomists, foresters, and any others who may be of particular importance in certain regions, for example, range specialists or pasture specialists ; an officer at each regional centre is also concerned with wildlife studies. A similar group of specialists is located at each project ; in addition there is a project soil conservationist whose duty it is

to contact the farmer and discuss with him the erosion control programme, explaining the Government's desire to co-operate with him by entering into a five-year co-operative agreement to demonstrate methods of soil and water conservation.

Preparation of co-operative agreement. This Agreement covers the operations, obligations and contributions by both co-operating parties and constitutes the Government's authority to assist the farmer in putting a definite programme into effect on privately owned lands.

After the farmer has indicated that he is interested in co-operating, economic and erosion surveys are made by the SCS. These surveys provide an inventory of the physical and economic conditions which is used as the basis for determining the conservation plan applicable to the individual farm. The conservationist and the farmer develop a land-use and conservation plan operative during the ensuing five years. The technical aspects of the plan are developed and checked by the various technical sections and co-ordinated by the soil conservationist into a plan of conservation operations that will meet the requirements of the land. The co-operative agreement is prepared, incorporating the plan and is signed by the farmer and the representative of the Government. Various phases of the operations are carried out by the technical section most concerned. It is the duty, however, of the conservationist to follow through and co-ordinate the fulfilment of the agreement and to make such amendments as may be necessary in carrying out the plan for the term of the agreement. This he will continue to do after the project is placed on a maintenance basis.

The project conservationist depends upon the other technical sections on the project for the technical details of the co-operative agreement. It is he, however, who must co-ordinate the various phases of the plan of conservation operations and make certain that they conform to the project working programme. In turn, the regional conservationist, with the aid of the regional technical staff, supervises the project programme and co-ordinates it with the regional plans. Likewise the Section of Erosion Control Practices, in co-operation with the other sections within the Division of Conservation Operations in the Washington Office, co-ordinates the regional programme with the national programme.

The early co-operative agreement covering both Soil Conservation Service and Emergency Conservation Work operations was very general and consisted mainly of an agreement to follow erosion-control practices not specifying in detail what those practices were to be. The old agreement was revised and the new co-operative agreement was approved by a conference of regional conservators in February 1936; this new agreement is more detailed than the old and gives the farmer co-operator a clearer understanding of the soil-conservation programme. The plan of conservation operations, cropping plan and land-use map are now a part of the agreement, wherein land-use planning, operations, practices, and obligations are set forth in detail. (See Appendix, p. 166.)

The erosion survey map shows the degree of erosion, present land-use, slopes and soil types and is used as a basis upon which to build future land-use plans. The land-use map is intended to show the proposed new land-use and to designate property boundaries, field boundaries, fence and crop boundaries, drainage outlets, roads, buildings, fences and field acreage. The standard cropping plan shows the rotation of crops, by fields, for the five year period of the agreement. The most important revision of the new co-operative agreement is the addition of the plan of conservation operations. This part of the co-operative agreement lists in detail all operations, practices, contributions and obligations, by fields, by each of the co-operating parties.

Forest Service

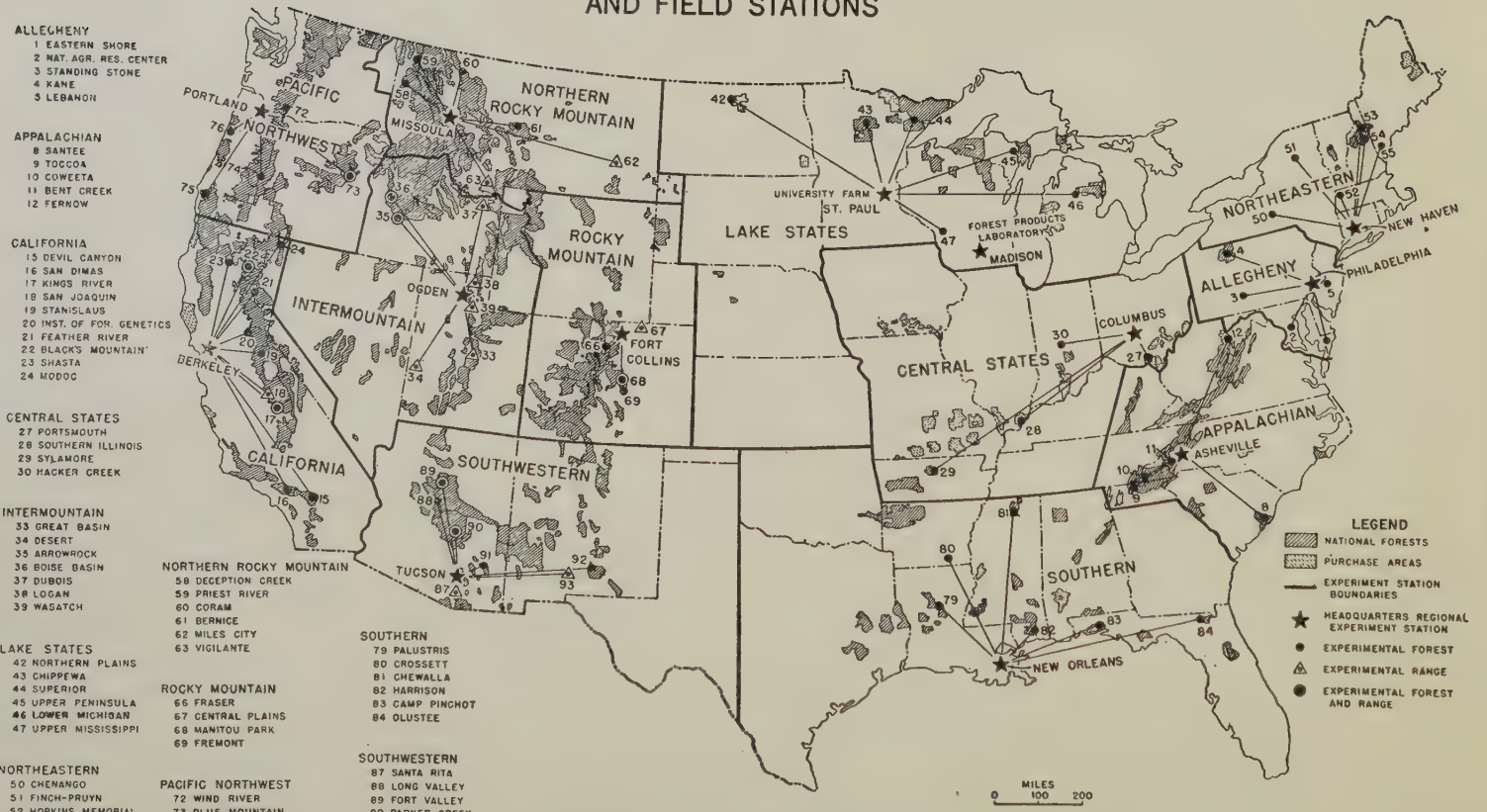
Research in forestry was under way in the Department of Agriculture before there was any other forestry activity in the Federal Government. Following the creation of the Forest Service, forest investigations were undertaken to develop methods of protecting the forests from fire, over-cutting, and overgrazing. In 1915 a Branch of Research was established in the Forest Service which unified the investigative effort and systematized the work under way. This led to the establishment of a series of regional forest experiment stations which now cover the country and supply the basic facts on which forestry programmes are developed.

In these stations is conducted work on all phases of forest research, emphasis in each region being placed on problems of greatest import. Included is research on silviculture, range management, influences, economics and products. Co-ordination and correlation are assured through the co-operative development of each station's programme. Office headquarters are located usually in cities having research or educational facilities, with field work conducted at a number of experimental forests and ranges. Some experimental areas are devoted entirely to silvicultural research, others to range research, and others to watershed research. But wherever possible, work in all three fields is combined on a given area.

Influence research, to determine the effect of natural cover on water, soil, and climate, has much in common with both range and silvicultural research. It attempts to work out land management methods that will yield maximum supplies of usable water at all times. Whole watersheds up to 15,000 acres are broken up into small basins, and each is studied in detail before any modification is attempted. Intensive studies are made of the precipitation, the run-off, and the erosion both before and after treatment. The most ambitious programme under way is that at San Dimas, California, where about $2,000,000 has been spent in developing the physical plant, including large reservoirs and a battery of over 200 lysimeters ranging up to 20 × 10 × 10 feet in size. This form of attack, developed in the Forest Service beginning in 1910, has now been rather generally adopted by many agencies having similar problems. The forestry literature is rich with the references to this work, which has

JUNE 1, 1937

FOREST SERVICE RESEARCH CENTERS AND FIELD STATIONS



ALLEGHENY
1 EASTERN SHORE
2 NAT. AGR. RES. CENTER
3 STANDING STONE
4 KANE
5 LEBANON

APPALACHIAN
8 SANTEE
9 TOCCOA
10 COWEETA
11 BENT CREEK
12 FERNOW

CALIFORNIA
15 DEVIL CANYON
16 SAN DIMAS
17 KINGS RIVER
18 SAN JOAQUIN
19 STANISLAUS
20 INST. OF FOR. GENETICS
21 FEATHER RIVER
22 BLACK'S MOUNTAIN
23 SHASTA
24 MODOC

CENTRAL STATES
27 PORTSMOUTH
28 SOUTHERN ILLINOIS
29 SYLAMORE
30 HACKER CREEK

INTERMOUNTAIN
33 GREAT BASIN
34 DESERT
35 ARROWROCK
36 BOISE BASIN
37 DUBOIS
38 LOGAN
39 WASATCH

LAKE STATES
42 NORTHERN PLAINS
43 CHIPPEWA
44 SUPERIOR
45 UPPER PENINSULA
46 LOWER MICHIGAN
47 UPPER MISSISSIPPI

NORTHEASTERN
50 CHENANGO
51 FINCH-PRUYN
52 HOPKINS MEMORIAL
53 GALE RIVER
54 BARTLETT
55 MASSABESIC

NORTHERN ROCKY MOUNTAIN
58 DECEPTION CREEK
59 PRIEST RIVER
60 CORAM
61 BERNICE
62 MILES CITY
63 VIGILANTE

PACIFIC NORTHWEST
72 WIND RIVER
73 BLUE MOUNTAIN
74 PRINGLE FALLS
75 PORT ORFORD CEDAR
76 CASCADE HEAD

ROCKY MOUNTAIN
66 FRASER
67 CENTRAL PLAINS
68 MANITOU PARK
69 FREMONT

SOUTHERN
79 PALUSTRIS
80 CROSSETT
81 CHEWALLA
82 HARRISON
83 CAMP PINCHOT
84 OLUSTEE

SOUTHWESTERN
87 SANTA RITA
88 LONG VALLEY
89 FORT VALLEY
90 PARKER CREEK
91 MT. GRAHAM
92 CLOUDCROFT
93 JORNADA

Map by courtesy of Forest Service, U.S. Department of Agriculture.

modified national and state policies in many respects. References are not quoted here because of lack of space and because this work deals more with agricultural problems.

Range research probably touches the agricultural problem most directly. It is organized at the six western forest experiment stations whose territory includes the 17 western states where grazing has developed on a large scale. The primary problems in range research are those of range forage, range management, artificial revegetation and watershed protection.

Range forage investigations deal with the identification, growth requirements, life histories and other ecological relationships, and forage and other values of range plants. Range management studies are made to develop methods of grazing, consistent with the conservation and use of other resources and include studies of systems of grazing (such as deferred and rotational), grazing capacity and proper seasonal use, and methods of handling livestock on the range. The principal objective in the artificial revegetation research is to develop methods and suitable species for seeding or transplanting range lands so badly depleted that reasonably rapid revegetation appears improbable. Of particular importance is the development of revegetation methods sufficiently low in cost to be economically feasible on a large scale on lands of low value.

The main objective of range watershed research is to perfect methods of managing ranges that will afford essential watershed protection and at the same time give maximum forage production. It includes studies of the relation of different types and conditions of vegetation to soil, run-off, percolation, use of moisture by vegetation, and delivery of usable water; erosion control primarily through vegetation; and the cost of control work that can be justified on range lands on an economic basis.

Because certain features of this work are highly specialized, advantage is taken of the facilities afforded by other Bureaux of the Department of Agriculture and in other Departments. As outlined by Talbot and Crafts (61), six other Bureaux in the Department of Agriculture either have cooperated with the Forest Service or have worked independently on related problems within their jurisdiction. For example, the Bureau of Plant Industry in the early days investigated certain phases of range revegetation, and more recently has devoted increasing attention to pasture problems, development of forage crops and plant breeding. The Bureau of Animal Industry has studied animal husbandry and poisonous plants, the Bureau of Entomology and Plant Quarantine, insect problems, and the Bureau of Chemistry and Soils, plant analyses and soil problems relating to range lands. The Bureau of Agricultural Economics currently estimates the number of livestock and range conditions and has studied cost of production and range organization. The Bureau of the Census of the Department of Commerce has periodically collected statistical data and the Tariff Commission has investigated manufacturing costs and returns on range products.

The State agricultural experiment stations in each of the seventeen

western states have individually undertaken work on a variety of problems, centring on range management, animal husbandry and economics. The Carnegie Institution of Washington and the Boyce Thompson Institute for Plant Research have both investigated problems that bear directly and indirectly upon range vegetation.

Research relative to erosion control and conservation of soil, water, and vegetation

Function and Scope of Division of Research, Soil Conservation Service

Office of Chief, Division of Research

The work of this Division is conducted through a Washington office and through six section offices whose principal work lies in the field where erosion is most acute. The Office of the Chief formulates, establishes and co-ordinates major research policies, reviews and helps to develop the working plans through which the research is carried out. In the field, the Chief and his staff inspect and supervise projects, suggestim proved procedures and aid in maintaining a proper scientific standard of research.

Soil and water conservation experiment stations

The studies under this project are directed towards developing and testing practices which are effective and practical for conserving and utilizing the soil and water resources on farm lands. The work is conducted from experiment stations, field stations, and laboratories representative of critical erosion problem areas, where local climatic conditions have produced similar problems of wind and water erosion. These investigations provide for the determination of soil and water losses under different land-use and farming practices and for different climatic, topographic, and soil conditions in various agricultural regions. In addition, the principal causes for soil and water losses are studied and this basic information is used in the development of practical agronomic and engineering methods for keeping soil and water on the farm. As conservation practices are developed and tested on the stations, they are applied to co-operating farms and their effectiveness is checked by conducting systematic evaluation surveys and practical field tests on work and demonstration projects.

Investigation of sedimentation resulting from erosion

The work under this project provides accurate information on the damage caused by sedimentation from erosion to reservoirs, stream channels, and to lower lying agricultural land. Detailed surveys are being made of the rate of siltation of reservoirs and channels which show the extent to which the application of soil conservation measures to watershed areas can be justified to protect the public investments in water storage facilities. Determinations are likewise under way of the impairment of productivity of valley lands caused by the deposition of the infertile products of erosion.

Studies are being made in natural streams to measure the total load of sediment carried and determine the manner in which sediment of different types contributes to filling reservoirs and stream beds. In addition, large scale laboratory investigations are being carried out to determine the hydraulic principles governing the entrainment, transportation and deposition of erosional debris.

Watershed investigations of the effect of land-use practices on run-off as related to methods of control of erosion and floods

Investigations are made of the behaviour of water from the time it reaches the land as precipitation until it leaves the watershed as surface or underground flow. An evaluation is being made of the effects of physical characteristics of the land and its use, such as soil, topography, size and slope of drainage pattern, vegetative and crop cover, surface and underground storage, tillage methods and erosion control practices, as they affect storm run-off, stream flow and flood flows. These investigations are conducted experimentally on entire watersheds of suitable areas and are carried out extensively by sampling plots for responses in run-off and erosion. Two intensive experimental studies and one extensive study are under way. The intensive studies include watersheds of approximately 5,000 acres each and are established, one in the Muskingum Watershed Conservancy District in Ohio, and the other in the Brazos River Conservation and Reclamation District of Texas. The extensive study is conducted within the Central Great Plains with headquarters at Lincoln, Nebraska. Determinations are also being made of the rates and amounts of run-off in agricultural areas within work project areas for use in the economic design of erosion control, flood flow control and hydraulic structures.

Investigations of the geographic and climatic factors related to erosion

This project is concerned with the study of the physical factors such as climate, plant cover and geographic environment, which notably affect soil erosion. Climatic studies are under way which attempt to delimit the climatic regions of the country in order to determine the frequency of storms and rainfall, and show their influence on soil erosion and the occurrence of droughts. Field studies are being carried out to find the relation of the bed rock, soil type, climate and vegetation to gully cutting, sheet wash and wind erosion. Ecological research is being used to determine the nature of plant succession on eroded areas and to find the best methods of controlling erosion through artificial plant covers. Studies in the history of erosion show not only its early occurrence, but also trace the attempts which have been made to correct the trouble, both in the United States and in foreign countries.

Investigations of the economics of soil and water conservation

The work under this project is designed to develop an economic

appraisal of the current soil-conservation programmes, and to provide suggestions for their improvement. This appraisal is being developed through a determination of the changes in the ownership, operation and financial organization of farms, ranches and orchards and in the income and standard of living of their operators, brought about both by erosion and by an erosion-control programme, as well as by the effect of the latter agencies on non-agricultural individuals, institutions and communities. Further, this appraisal involves a determination of the damage sustained by the public through the destruction of land by erosion, the accumulation of erosion debris on roads, in streams and in reservoirs ; the cost to the public of erosion control ; and finally, a measurement of the public benefit to be gained from a co-ordinated programme of soil and water conservation.

Co-operative investigations of erosion-resisting plants of economic value ("Hill culture")

Many millions of acres of agricultural land must be retired from clean-tilled cultivation incident to accomplishing the national programme of soil and water conservation. The annual cash returns from uncultivated vegetation, such as ordinary forest cover or pasture, are frequently too low to justify the average farmer in discontinuing cultivation to the extent called for in the erosion control plans. The work of this project is centred on the attempt to find superior types of erosion-resisting plants and covers having high economic possibilities. Tests are being carried out with such plants on a variety of soils to determine their adaptability to different climatic regions and to improve vegetation methods for the dual purpose of erosion control and economic use. Experiments are being initiated on the selection and breeding of new plants, as well as on economical methods of propagation. Research is also planned on the utilization of the products, which it is hoped may have a wide variety of uses ranging from human and livestock food to new sources of tannin, fibres and vegetable oils. The work is done in co-operation with many State and Federal subject matter agencies (25 and 14).

Soil Conservation Experiment Stations

The practical methods employed in the soil conservation programme during the early years of the operation of the Soil Conservation Service were in many cases purely empirical, and not based upon the result of actual scientific experiments. Only now are the results of the comprehensive experiments at the conservation experiment stations established under the Federal appropriation of 1930 being published. Examples of such reports are those from Clarinda, Iowa (56), Pullman, Washington (70) and Guthrie, Oklahoma (71) ; before reviewing the Clarinda report (those from Pullman and Guthrie are not available for general distribution outside the SCS), it will be appropriate to give a list of the various projects studied or proposed at one of the oldest of the Soil Conservation Experiment Stations at Bethany, Missouri, since 1930. Similar studies are in

progress at the other SCS Experiment Stations, with variations to suit the local conditions in each case. It is obvious that a wealth of information is being collected at all these Stations which should be of great value in formulating erosion-control practices in the United States and in all other countries affected by the erosion problem.

Bethany, Missouri.

The main object of the research in this centre in the Missouri-Iowa region is to determine the variables affecting the rate and amount of erosion and run-off on the Shelby loam and possibly other important regional types, and to study the fundamental processes relating to these losses with a view to developing practical measures for minimizing or controlling them, as follows :—

(a) The effects of cropping treatments on the relative and total losses of soil and water and the relation of erosion to chemical and physical properties of the soil on various slopes.

(b) The efficacy of modifying the soil and subsoil by cultivation, such as (1) subsoiling, (2) strip subsoiling, (3) rough cloddy temporary fallowing, (4) the digging of water-saving holes and the replacing of every third or fourth row with a deep water furrow, in reducing run-off and erosion.

(c) Development of methods for restoring productivity to severely eroded land, if possible.

(d) The effect of soil-incorporated organic matter on erosion and run-off.

(e) Determination of relative value of special practices, such as strip cropping, crop rotations, etc., as a supplement to terraces in some cases.

(f) Relation of soil and water losses, yield and quality of crops.

(g) Relation of cropping systems, including different proportions of corn on terraced and unterraced land, to erosion, run-off and yield.

(h) Relation of native sod and planted grasses to soil and water losses and the effect of moderate and intensive grazing on these losses.

(i) The use of trees, shrubs, vines and grasses in gully and terrace outlet control.

(j) Depth of penetration and retention of moisture under terraced and unterraced conditions and under other critical conditions of soil treatment.

(k) Relation of crop rotations and soil treatment on terraced and unterraced areas to erosion and run-off control.

(l) Effectiveness of artificial structures, such as terraces, on relative and total losses of soil and water.

(m) Effectiveness of various types of dams, including " living" or grass dams and of various vegetative covers in controlling gullies, incipient field washes, terrace outlets, etc.

(n) Rate of movement of soil down slopes which have been terraced or otherwise treated.

(o) Run-off and erosion from small watersheds in relation to precipitation of various magnitudes and intensities, slopes and soil characteristics and surface conditions.

(p) The most economical type of terrace construction.
(q) The most economical methods of field operation of farm machinery on terraced lands.
(r) Terracing machinery designed for operation over terraced areas.
(s) Effects of direction of crop rows with respect to terraces and slopes on terrace capacity and maintenance.
(t) (1) The extension of laboratory and small plot results or findings to larger scale field experiments approaching practical farm operations, (2) the extension of these results, as well as any observed local farm practices, to field use on a co-operative basis.
(u) Effects of tile drains in erosion control.
(v) Study of the regional erosion problem as relating to extent of damage, economic losses and possibilities of extending remedial measures.

Clarinda, Iowa.

The methods of measuring soil and water losses adopted in the classic experiments of M. F. Miller at the Missouri Agricultural Experiment Station in 1917, A. B. Conner and R. E. Dickson at Spur, Texas (commenced 1926), and the Bureau of Public Roads at Raleigh, N.C. (commenced 1924) (see ref. 56, p. 2) were available as patterns when the Clarinda experiments were laid out in 1930. New experiments have since been installed which show great improvements in general plan as compared with the old patterns.

The experimental plan at Clarinda (56) is similar to that outlined for Bethany. The primary purpose is a quantitative study of the soil and water losses and their causal factors. It is desired to discover the methods that may be used for retarding the losses of soil and water, and particularly the practicable methods of retarding the movement of soil-carrying water. It is also desired to learn what methods may be used to renew the fertility of eroded lands in order that they may be used for a profitable type of agriculture.

Other incidental objects include the acquiring of data relating to the effects of erosion and water losses upon crop yields ; the type of agriculture most suited to the problem area ; the cost of control measures for retarding soil and water losses in relation to the monetary damage caused by such losses, and the general practicability of various specific conservation practices for wide application upon the soils of the Missouri Valley loess problem area.

Preliminary data on canopy interception indicate the importance of the subject and the marked effects which varying types of vegetation may have in the protection of the land surface. It seems probable that the interception of rain by the plant canopy may readily account for a considerable portion of the control of erosion and run-off which is so commonly noted for alfalfa, clover, blue grass and even small grain and corn (maize) when the latter are fully developed.

The two important soils of the problem area show marked differences

in relative infiltration by water, the Marshall silt loam having an infiltration rate from 7 to 10 times that of the Shelby silt loam. This difference is sufficient in many instances to represent a greater total amount of water than that which is placed under control by common treatments. The infiltration studies have been extended to determine some of the more important factors which affect the rate of run-off and erosion on these two soils, with the result that soil porosity is indicated as perhaps the most important single factor. The soil moisture content and the vegetative cover are of less importance in their effect upon the infiltration rate. Soil moisture apparently reduces infiltration on these two soils approximately in proportion to the space volume which it occupies. Vegetative cover may increase total infiltration through its effect in reducing the rate of run-off. It is doubtful whether any increase in rate of infiltration may be attributed, for example, to root effects of growing plants. Insofar as vegetative cover prevents the application of turbid water to the soil profile normal infiltration is maintained thereby, as has been shown by other investigators.

The increase in soil porosity resulting from the application of organic matter to the surface of a normal profile has comprehensive effects upon water conservation. Such treatment has significantly (1) increased percolate through 3-feet profiles of both permeable and relatively impermeable soils ; (2) decreased run-off and (3) increased the store of potentially available water. Such treatments have not exerted any marked effects upon evaporation and have reduced erosion by large amounts. The potentially available water, that is, rainfall less run-off, has been increased by about two surface inches a year in the Marshall and by about 1.6 surface inches a year in the Shelby soil series by these treatments.

The relationship between land slope and the capacity of surface-impounding treatments has been shown. As the land slope is increased, impounding is decreased so rapidly that a treatment which will impound 2.5 inches on level land will impound less than one-fourth as much on a 15 per cent slope. This is an important consideration in connexion with the design of control measures for different land slopes.

Other aspects of the problem discussed in the Clarinda report include the effect of various treatments in reducing run-off under various crops (bluegrass, alfalfa, clover, contour-listed corn), and the factors governing the density of run-off. The effect of adding organic matter to Marshall silt loam, which was excessively eroded, was greatly to reduce run-off and erosion and markedly to increase soil moisture, rate of growth and yield of corn.

The type of strip cropping suitable to the permeable Marshall silt loam was found to differ considerably from that generally used on less permeable soils in the United States. Combining primarily the effects of surface impounding and infiltration, theoretical protection, equivalent to the maximum rain to be expected in a period of 15 to 20 years, may be secured through minor modifications of present farm practices. The

study of slope lengths has revealed the uncertainty which arises when attempting an estimate of the optimal width of crop strip.

Research on factors influencing erosion and soil erodibility

It is impossible to review the mass of literature on erosion experiments which is being produced in the United States ; a few typical studies on these problems are discussed below. Other papers and research will be mentioned incidentally in the sections on regional problems and their control.

Soil factors influencing erosion

Baver (3) grouped soil factors influencing erosion into those which affect run-off and those which affect the movement of water when run-off occurs. The chief factors affecting run-off are the water-absorbing properties, particularly the rate at which a soil can absorb water, rather than the total amount absorbable. Both rate and amount are functions of, and increase with, coarseness of texture and degree of aggregation, but they are greatly affected by the structure of the whole soil profile, especially by impermeable sub-surface horizons. Dispersibility influences the erosion caused by run-off, since, in general, appreciable movement of soil will only take place when the particles are suspended in water. Texture also influences solifluction, the coarser particles requiring a higher velocity of water than the finer to transport them. From these considerations Baver proposed the following formula to express the relation of erodibility to the main soil factors affecting it :—

$$E = \frac{KD}{A\ Pp.}$$

where E indicates the erosion under constant climatic, topographic and vegetation conditions ; D the dispersibility ; A the absorption capacity for water ; P the permeability ; p the particle size ; and K a proportionality constant. In other words, erodibility is directly proportional to dispersibility, and inversely to absorption capacity, permeability and particle size.

Middleton's (43) study on soil properties influencing erosion is widely known and frequently quoted*, and his results will only be briefly summarized here. Of sixteen physical properties investigated, he was able to correlate erodibility with only three, namely :

Dispersion rate (D.R.).
Ratio of colloid content (0.002-0.005 mm.) to moisture equivalent (C.E.).
Erosion ratio (E.R.).

The erosion ratio is given by E.R.=D.R./C.E. The dispersion ratio is the percentage of the total clay + silt, as given by mechanical analysis,

*See, for example, Imperial Bureau of Soil Science, Technical Communication No. 28.

remaining in suspension after the soil has settled in a column of water until no particles greater than 0.05 mm. remain suspended above 30 cm. depth. D.R. may be regarded as directly related to dispersibility and inversely to water-holding capacity; C.E. is directly related to water-holding capacity and inversely to permeability. The relationships, however, are not proportional. Some results obtained by Middleton are given in the following table, taken from Technical Communication No. 28.

Group			Dispersion ratio	Erosion ratio
I.	Erodible soils.	Memphis silt loam ..	66.0	115.8
		Orangeburg sandy loam	16.9	12.4
	Non-erodible soils.	Nipe clay ..	6.1	2.9
		Aiken silty clay ..	15.1	8.7
II.	Erodible soil.	Iredell loam ..	19.6	24.2
	Non-erodible soil.	Davidson clay loam ..	13.3	12.2

It will be seen that there is a rough correlation between erosion ratio and erodibility, but it must be admitted that the soil properties involved (D.R. and C.E.) are somewhat artificial. Middleton and his collaborators (46) recognize that the erosion ratio has only a qualitative significance. Erodibility, however, is usually evident in soils with erosion ratios of 10 or over.

Bouyoucos (5) found that the " clay-ratio "—(sand + silt) : clay—with few exceptions paralleled Middleton's erosion ratio, and was easier to obtain.

Slater and Byers (44) considered that permeability was the property most likely to be related to erodibility. The rate of percolation was inversely related to the silt content. They proposed a " percolation ratio " as a criterion of erodibility. The percolation ratio,

$$\text{P.R.} = \frac{\text{Per cent suspension} \times \text{moisture equivalent.}}{\text{Per cent colloids.}}$$

$$= \frac{100 \times \text{E.R.}}{\text{Per cent silt and clay.}}$$

As regards chemical properties, Bennett (4) has shown that low silica-sesquioxide ratios are associated with non-erodible soils of low plasticity and great permeability and porosity, exhibiting deep, homogeneous profiles in which the downward eluviation of the finer soil particles is small. The work of Middleton, Slater and Byers (46) on the soils from the American Erosion Experiment Stations revealed no general relationships between erodibility and chemical properties. The properties studied were the ratios SiO_2 : R_2O_3, SiO_2 : total bases, SiO_2 : water of soil acid, in the soil colloids. Strict comparisons between different soils were, however, difficult owing to the varying colloid contents which exercise a

large but irregular influence on erodibility. On the assumption, which was not fully substantiated, that a soil's erodibility is inversely related to the colloid content, slight indications were obtained that high silica-sesquioxide and silica-base ratios might be associated with high erodibility. "It may as well be admitted," state the authors, "that the colloid composition in itself plays a secondary role in erosion."

Vegetation factors affecting erosion

It is axiomatic that a natural vegetation cover should prevent erosion above the "geologic norm." Main interest attaches to the effect of cultivated and other artificially induced plant covers on erosion. As regards cultivated crops, erosion is affected more by the type of cultivation than by the botanical nature of the crop. Smith (see ref. 33, p. 102), indeed, attributes north-western Europe's immunity from widespread erosion partly to the fact that neither maize, cotton nor tobacco is grown there. These widely-spaced crops are undoubtedly the three most commonly associated with erosion in the United States. Grain crops hold the soil better, but still leave it exposed for considerable periods. Pastures and grass crops in general are very efficient unless overgrazed, and even moderate trampling by stock may increase run-off by consolidating the soil.

Ayres (1, p. 32) has tabulated some results obtained by Dodge (15), showing the relative holding power of different plant covers on Shelby and Lindley loams in Iowa.

Qualitative Comparisons of Holding Power of Various Kinds of Vegetation

Average run-off corrected for modal slopes			Average silt loss corrected for modal slope		
Relative rank	Plant	Unit index	Relative rank	Plant	Unit index
1	Hazel brush	0.48	1	Hazel brush	0.0
2	Oak-hickory	0.93	2	Oak-hickory	0.0
3	Timothy-clover	1.00	3	Sweet clover	0.013
4	Wheat, across slope	1.06	4	Timothy-clover	0.023
5	Sweet clover	1.18	5	Alfalfa	0.026
6	Barley	2.24	6	Ragweed	0.047
7	Alfalfa	2.89	7	Weeds after corn	0.048
8	Ragweed	3.54	8	Barley	0.078
9	Weeds after corn	4.20	9	Dog fennel grass	0.085
10	Corn	4.58	10	Wheat, across slope	0.11
11	Wheat, down slope	4.91	11	Oats	0.13
12	Sudan grass	5.25	12	Wheat, down slope	0.25
13	Soybeans	6.22	13	Sudan grass	1.58
14	Dog fennel grass	6.56	14	Corn	2.04
15	Oats	6.66	15	Sorghum	2.72
16	Sorghum	7.74	16	Soybeans	3.02

The figures are corrected for modal slope (the average slope was 10.97 per cent), but not for variations in soil and other factors, and therefore have only a qualitative significance. Ayres points out that the " plants vary in ability to prevent losses almost in direct proportion to the degree of their natural environmental adaptation." There is a general, though not complete, similarity in the relative efficiencies of the covers in preventing both run-off and erosion, but run-off appears to be the more sensitive to changes in vegetation. Musgrave (31) concluded that the " infiltration capacity," which is an important factor affecting the amount of run-off, was inherent in a soil's genesis and was largely unaffected by cultural treatment or cropping.

The effect of rotating crops on checking erosion is often out of all proportion to the mean effect of the separate crops. Miller (29) gives the following figures showing the average annual erosion and run-off under different cultivation.

AVERAGE OF 14 YEARS' MEASUREMENTS OF RUN-OFF AND EROSION, MISSOURI EXPERIMENT STATION, COLUMBIA. (SOIL TYPE—SHELBY LOAM. LENGTH OF SLOPE, 90.75 FEET. DEGREE OF SLOPE, 3.68 PER CENT)

Cropping system or cultural treatment	Average annual erosion per acre in tons	Percentage of total rainfall running off the land
Bare, cultivated, no crop	41.0	30
Continuous corn	19.7	29
Continuous wheat	10.1	23
Rotation—corn, wheat, clover	2.7	14
Continuous bluegrass	0.3	12

The mean erosion from the continuous corn, wheat and bluegrass plots is about 10 tons, compared with 2.7 tons from the rotated plot. Apart from the longer time the soil is covered by the rotation, Miller ascribed the good effect to the organic matter added by the clover, which improves soil structure and water-holding capacity. He divided the most important crops grown in Missouri into four classes according to their erosion-inducing effects, namely :—

Crops allowing much erosion	Crops allowing moderate erosion	Legume sod crops allowing little erosion	Grass sods allowing little erosion
Corn	Wheat	Alfalfa	Bluegrass
Cotton	Oats	Red clover	Red top
Tobacco	Barley	Alsike clover	Timothy
Soybeans (in rows)	Rye	Sweet clover	Orchard grass
Potatoes	Soybeans (drilled)	Korean lespedeza	

Since all plants act as some check on erosion, their efficiency will vary from region to region according to the climate, tending to be greatest where the heaviest rains coincide with the late growing season, when the

soil is best protected. Weaver's data (cited by Miller) showed that wheat 36 inches high was 3½ times as efficient in checking erosion as 3 inches high, maize 75 inches high was twice as efficient as 9 inches high, and Sudan grass 56 inches high was 5 times as efficient as 10 inches high. The increased protection obtained with growth indicated the important part played by the horizontal spread of the plant cover, in comparison with the lesser parts played by the roots and the vertical growth.

McIntyre (27) has shown that roots play a certain but subordinate role compared with the forest canopy and litter in soil protection. A coniferous canopy offers better protection against the beating action of rain than a less permanent and normally less dense deciduous canopy. Broad leaves, moreover, collect water which ultimately falls in the form of heavy drops. Coniferous trees produce a litter and humus layer more readily than deciduous trees, but the latter normally allow a richer ground flora to develop whose protective effect may outweigh other less favourable influences. Taking everything into consideration, the mixed forest, combining the soil-preserving effect of deciduous trees with the soil-protecting effect of conifers, is probably the most generally desirable. McIntyre mentions that the action of predatory insects and animals in producing spreading growth and crowns may be beneficial in checking erosion, however unwanted it may be silviculturally.

Slope factors affecting erosion

Several studies have been made of the effect of the nature of a slope on run-off and erosion. Duley and Hays (16) found that run-off increased rapidly with slope from 0 to 3 per cent gradient, and thereafter very slowly, whereas erosion increased slowly from 0 to 4 per cent gradient, and thereafter with increasing rapidity. A table in Parkins and Whitaker (33, p. 86) illustrates further the connexion between erosion, run-off and slope gradient, and also the greater significance of the vegetation as compared with the slope factor in determining erosion, since under the protective grass cover no loss occurred even from a 16 per cent slope. The Kirvin loam is described as highly erodible, the Nacogdoches (lateritic) loam as non-erodible.

Loss of Soil and Water from Kirvin and Nacogdoches Soils, East Texas

Soil	Slope per cent	Soil loss, tons per acre		Water-loss, per cent precipitation	
		Cotton	Grass	Cotton	Grass
Kirvin fine sandy loam ..	8.75	19	0.2	20	1.5
Kirvin fine sandy loam ..	16.50	35	0.0	13	0.7
Nacogdoches fine sandy loam ..	10.00	6	0.02	15	1.4

The effect of length of slope has been investigated by Duley and Akerman (17) in carefully controlled experiments with a silty clay loam on bare plots with a gradient of about 1 in 25, and 10, 20, 40 and 100 feet in length. They found that run-off was greatest from the short plots, both with heavy (e.g. 1 inch in 15 minutes) and with light (1 inch in 60 minutes) applications of water sprinkled on to simulate rain. The results for erosion were less consistent, but on the whole, the short plots eroded most under light applications of water and the long plots under heavy applications. The authors argue that the lesser run-off from long slopes is due to the water having more time to be absorbed by the soil. It was observed that the decrease of run-off with length was less, the longer the slope, probably owing to the water at the bottom becoming saturated. With considerably longer slopes than those used, therefore, it might have been found that run-off began to increase with length. The greater erosion from short plots under light applications of water is directly attributable to the greater run-off from these plots. Under heavy applications of water, when the rate of erosion is high, the increased carrying capacity and cutting power of the water, which tends to concentrate in definite channels on the longer slopes, more than offset the effect of the larger run-off from the shorter slopes.

For practical purposes, the Soil Conservation Service distinguishes four slope classes, on the basis of their optimal utilization and without reference to gradient or length, viz. (75) :—

Class A. Slopes requiring no particular erosion-control measures, other than proper crop rotation.

Class B. Requires erosion control when clean-tilled crops are included in the rotation.

Class C. Unsuitable for clean-tilled crops; recommended for pasture, hay, or other close-growing crops.

Class D. Should be left or put under forest or pastures, depending on the original vegetation.

Normally, Classes A to D represent a series of increasing gradients in any given region, but a Class A slope in one region may be steeper than, say, a Class B slope in another.

The regional problems and their control

The following account describes, with unavoidable gaps and generalizations, the conditions in the different regions and the conservation measures which are being adopted and recommended for the control of erosion and its related problems.

North-Eastern States

The erosion problem in the north-eastern part of the United States is generally not so severe as in other sections, and is one of prevention rather than cure, namely, the preservation of further soil and water losses by the various recommended methods, such as reforestation, establish-

ment and maintenance of good pasture and forage crops ; contour strip farming ; retirement of steep lands from cultivation ; proper care of tree lands ; the use of soil-building crops ; maintenance of proper crop rotations ; careful engineering. Deforestation has been excessive in some areas, and steep slopes have been cultivated which should not have been cleared. In the cultivation of arable land, the proper cultural practices have not been observed ; rotations suited to local requirements have not been used, ploughing and cultivating have been done up and down slopes instead of on the contour. Mismanagement of pastures led to deterioration of botanical composition with a consequent increase in the proportion of bare ground subject to erosion. Like so many parts of the United States, the area is subject to torrential rainfall over short periods.

The methods adopted for the conservation of soil and vegetation in Region 1 (see map, p. 131) include the reversion of slopes above a certain percentage to woodland, less steep slopes to be kept in pasture, with or without contour furrows (38, 32, 11, 7 and 26). Cultivated crops are to be grown in strips where necessary, with alternation of arable with hay or pasture strips, cultivated on the contour, and with or without terraces when the run-off from one strip to another is excessive (54).

Grassed spillways are necessary with terraces, possibly combined with constructional works, such as large or small dams. In some areas where fields are small and hedges run up and down hill, it may be advisable to remove these in order to facilitate working the field with tractor implements.

The importance of introducing proper rotations of crops into farm practice is being stressed in all parts of the United States ; the recommendations must necessarily be variable and flexible, according to the chief crop of the region concerned, for example, cotton, corn, wheat, etc. (41).

Where gullying is already severe, suitable measures must be taken ; these include natural control and reclamation by seeding grasses or planting trees, or the construction of soil-saving dams of a suitable type (40). The black locust (*Robinia pseudo-acacia*) is of particular value in gully control ; it makes rapid growth on good soils, grows even on poor and dry soils, is easily propagated, and produces very durable wood (42).

In a region where the production of milk is so important for supplying the great centres of population, pasture improvement is obviously of primary importance. The programme of research at the Regional Pasture Laboratory has already been described (p. 125) ; other important centres of research on pasture problems which have a direct bearing on the erosion problem are Cornell University, Ithaca, N.Y., and Storrs Connecticut Agricultural Experiment Station (6). At Cornell, Johnstone-Wallace (22) has found that wild white clover (*Trifolium repens*), which is widely distributed in pastures throughout the north-eastern States, provides almost complete control of soil erosion and greatly reduces the loss of water by run-off from the surface during heavy rains. This is due to the protective sward which prevents impact of raindrops with the soil ; to the

retarding of the rate of flow of water over the surface ; and to the increased porosity of the soil resulting from the accumulation of organic matter and the activities of earthworms. Applications of superphosphate and lime are important in the production of a high-quality, erosion-resistant sward of the clover with suitable grass species.

The Soil Conservation Service in co-operation with the Department of Agronomy of the New York State College of Agriculture at Cornell University has laid down a series of experimental plots of grasses and clovers and their mixtures at the Arnot Forest Experiment Station, near Ithaca, N.Y. Investigations are in progress to determine the influence of these plants upon erosion control and upon the nature of the soil at varying levels of fertility. A somewhat similar series of plots is laid out at Pennsylvania State Agricultural Experiment Station.

Other more particular conservation problems in the eastern States concern orchard and truck crop areas. Trials are in progress with contour strips of different widths in orchards, grasses or legumes being used in rotation. In the truck crop area along the eastern seaboard, a special type of rotation and special cultural methods have had to be evolved on the particularly erodible soil of the area, where cultivation of even 2 per cent slopes leads to marked erosion.

It should be noted that in this Region, and in those to be described later, demonstration projects have been organized in typical watersheds, the farmers being enrolled in the manner described on p. 132. Most projects contain one or more Civilian Conservation Corps (CCC) Camps, which supply labour for the various constructional and other works which the Government agrees to undertake on farmers' lands. Representative projects in varying soil and climatic areas throughout the country are also used for special hydrological studies, measurements being made of the amount of water flowing from plots, fields, farms and finally complete watersheds. Where these water gauges are set up at the initiation of a project, comparative data will be obtained over a number of years (a project is maintained for a five-year period), from which it will be possible to measure accurately the effect of the various conservation measures adopted, in terms of run-off water.

Tennessee Valley

A particular type of conservation work has been in operation in the Tennessee basin for some years and deserves special consideration here. This regional reclamation project, administered by the Tennessee Valley Authority (TVA) affords a good illustration of the difficulties likely to be encountered in regional planning in the United States, and of the successful outcome of overcoming those difficulties. The Tennessee basin is a natural region covering an area of about 40,000 square miles, with a population of 2,500,000 and includes territory in seven States. The rainfall varies from under 40 to over 80 inches, and the altitude from 325 to 6,700 feet (2). Originally the whole region was forested, the higher

ground is still timbered, but erosion has seriously impoverished most of the agricultural land. The average annual income of 4,000 families that were moved when the Norris reservoir was being built was less than 100 dollars. The Tennessee River is a tributary of the Ohio River and contributes a considerable quota to the recurrent Ohio and Mississippi floods.

The notorious destitution of the region has produced in the past several abortive schemes for social and land improvement. These failed partly because they were not conceived on a sufficiently comprehensive scale and because the sanctity of State rights precluded the possibility of putting any such scheme into operation. These State rights were a main obstacle to be overcome before the TVA could plan any reclamation project embracing the whole region, consequently it has had to express its objects somewhat indirectly. Barbour (2) states: "The charter governing the operations of the TVA is careful to emphasize the navigation and flood-control aspects of its functions. Under the Constitution of the United States, a sharp distinction is drawn between the fields of State and national legislation. In contrast to the localized character of the advantages gained from better irrigation and power systems, the benefits of improved trunk river communication and flood-control extend beyond the limits of any one State, and thus become questions in which Federal actions or intervention can be legally justified. The NRA (National Recovery Act) became a dead letter after it had been successfully challenged in the Supreme Court on the ground that Federal interference had exceeded constitutional limits by usurping functions reserved for State legislations. But while legal attempts on the part of utility interests to prove the TVA unconstitutional oblige the latter to base its claim to existence on river regulation works, in practice, and from the wider geographical standpoint this aspect seems less important than the anticipated by-products in schemes for economic rehabilitation."

The TVA has no capital stock. It is controlled by the Federal Government and financed by Congress. Its main source of income is from the sale of electric power, the use of which is stimulated by low prices. But it is unlikely that the TVA will ever be completely self-supporting.

The TVA's principal stated function of developing the Tennessee River for navigation involves erecting a series of dams as a first step towards ensuring a permanent nine-feet-deep channel under all circumstances of flow. Satisfactory maintenance of the navigation channel involves flood control which, in its turn, involves erosion control, re-settlement of a large part of the farming community and complete re-organization of land-use. At the same time the dams, under proper flood and erosion-control conditions, should supply a steady flow of water to be converted into the cheap electricity from which the TVA draws its income. Thus regional erosion control, planned independently of State boundaries, has become a first essential to the execution of the Federal scheme for making the Tennessee River navigable. Private utility interests that objected to federal competition in supplying electricity have been accommodated by the TVA selling its current to them to be retailed at a fixed, low price.

On moderate and steep slopes erosion control is being effected by using check dams and brush mulches as temporary checks until reforestation makes the control permanent. In a year and a half 86,000 check dams were built and over 7,000,000 trees were planted (2). Gentle slopes are re-graded and planted with grass. These measures serve not only to preserve and reclaim the remaining soil, but equally to prevent siltation of the reservoirs constructed in connexion with the hydro-electric and navigation schemes that form an essential part of the whole regional plan. It is estimated that the anti-erosion measures now being taken will prolong the life of the great Norris reservoir from 100 years (estimated on the former rate of siltation) to 700 years.

The extreme depletion of the soils and the penury of the farmers present special difficulties in devising an agriculture that will be at once economic and conservative. Some of these difficulties are being overcome by converting a huge nitrate-producing plant, constructed during the war for munitions, to produce cheap phosphates. This plant, at Muscle Shoals, is operated in connexion with the Wilson Dam which can also supply large quantities of electric power. The TVA now produces phosphatic fertilizers at one-third of the commercial price for local consumption. It is believed that by using cheap fertilizers it will be possible to rest exhausted land or convert it to pasture, introduce livestock and diversify crops, while at the same time securing a higher net income for the farmer.

One of the most important features of the TVA's plan is the interdependence of its parts. The navigation scheme cannot succeed without erosion control; regional erosion control could not have been carried out without the navigation scheme. Erosion control and navigation are linked up with flood control, reforestation, re-settlement of the population, electricity supply, the production of fertilizers, agricultural improvement, etc. All these have to be properly co-ordinated by a competent central authority if success is to be achieved. The TVA employs about 13,000 persons, including 4,000 skilled technicians and clerks. Its salary list includes almost every recognized profession and some that would scarcely be recognizable outside the Tennessee Valley. The cost of the projects and improvements destined to be completed by 1943, when the TVA will be ten years old, is estimated at 350-400 million dollars.

South-Eastern States

Some of the most sensational gully and sheet erosion to be found in the United States has occurred in the Piedmont country lying in the five States of Virginia, North and South Carolina, Georgia and Alabama. The region is the rolling foothill country of the Appalachian Range, and extends east and south to the fall line which separates the Piedmont from the broad, gently sloping Atlantic and Gulf Coastal Plains (53). This region covers about 40 million acres; according to the reconnaissance rosion survey completed in 1934, three-fourths to all of the topsoil has

been washed from about 12 million acres and great sectors of the area are disfigured and defaced by gullies. Most of the remaining 28 million acres has suffered in varying degrees. The degree of damage caused by erosion increases as one goes southward. There are millions of gullies in the Piedmont ; in some types of soil, gully cutting goes on slowly, in others, especially those derived from granitic rocks, the process goes on slowly until the clay subsoils are worn through and becomes rapid when the soft " rotten " or disintegrating rock which underlies the clay is reached. Advanced erosion accounts in a large measure for the retirement from cultivation of some 50,000 farms between 1920 and 1930, in the Piedmont of the Carolinas and Georgia.

As a result of this excessive erosion, bottom lands have been buried by the deposition of eroded material ; in an area famous for its water power resources, 13 out of 56 of the larger reservoirs in the southern Piedmont are now completely filled with silt.

A number of soil saving practices have stood the tests of practical use and are being introduced into local farm schemes of defensive soil husbandry.

Late in the nineteenth century, Priestly Mangum, a farmer at Wake Forest, N.C., made the first great contribution to terrace design, creating the type of broad-base terrace which bears his name. The Mangum terrace was stronger and broader than the types previously used, being 12 to 15 inches high and 18 to 24 feet broad ; it may be described as a levee of earth built to direct water safely from a field and to conserve water by causing it to sink into the ground above the embankment. About 1924, M. L. Nichols, of the Alabama Polytechnic Institute, designed a broad-base terrace superior in some respects to the Mangum type for certain soils ; the Nichols terrace is now being widely used in SCS demonstration areas in South Carolina, Georgia and Alabama (55). It is essentially a broad, shallow ditch buttressed on the lower side by an embankment of earth ; it is built entirely from the upper side by moving the soil down from above. Most of the water behind the terrace flows in a channel below the original surface of the ground and complete terrace failures are rare. The Mangum terrace differs in that it relies more upon a broad embankment of earth to hold the water ; one third of the soil is moved uphill and two-thirds downhill. The Mangum terrace is an intercepting and absorption structure, the Nichols terrace an intercepting and drainage structure. On the deeper sandy soils along the Atlantic and east-Gulf Coastal Plain, the more expensive Mangum terrace is preferred ; for most Piedmont soils the Nichols terrace is superior. The grade of the modern broad-base terrace is variable, increasing progressively as the terrace approaches its outlet. Obviously the type, grade and distance between terraces vary widely according to local conditions ; a complete consideration of the technique of terrace construction is given by Ayres (1).

A terracing system on a farm is incomplete unless the water is directed

from a field through a system of protected waterways on a stabilized grade ; the lay-out and protection of these field waterways are among the most difficult points in terrace construction. A popular method is to lead the terraces to a natural draw, which is seeded (preferably some time before the terraces are constructed) to a thick-growing meadow crop such as a mixture of grasses and legumes ; perennial native grasses with tough fibrous root systems are suitable, if they are not liable to rank growth which would reduce the capacity to discharge. Bermuda grass (*Cynodon dactylon*) is suitable in the South, although centipede grass (*Eremochloa ophiuroides*) or carpet grass (*Axonopus compressus*) may be substituted. The SCS recommended mixtures are given by Ayres, pp. 193-4 (1).

Terracing yields better results on some types of land than on others. Terracing alone is probably adequate for stabilizing some soils in fields of gentle slope ; on other slopes and soils, it fails to provide stability unless supported by other measures such as crop rotation, planting winter and spring cover crops (50), and strip cropping. The value of these conservative measures to the Piedmont country is described in a Farmers' Bulletin (53). Other practices of value include contour-furrowing of pastures and the use of vegetation in gully control ; there is a wide variety of plants suitable for gully-control work in the Piedmont. Kudzu (*Pueraria thunbergiana*) is the most promising species (45).

Early in the 1930's, it was suggested that the farmers of the Piedmont should pool their resources, obtain adequate equipment and act co-operatively. The movement started in Alabama, groups of farmers organizing terracing clubs to raise the money necessary for the co-operative purchase of equipment for constructing Nichols and Mangum terraces. The idea spread to Georgia and other States ; in a short time the original purposes of the terracing clubs broadened and the clubs grew into soil-conservation associations. Sponsored by the SCS and the State extension services, associations are now being formed in many States (see p. 163).

Corn Belt States.

The Upper Mississippi Region of the SCS (Region 5), comprising the States of Minnesota, Wisconsin, Illinois, Iowa, and Missouri, contains half the first-grade land in the United States. A study of soil erosion in Iowa may be taken as a typical statement of the conditions in this Region. In 1934 the SCS in co-operation with Iowa Agricultural Experiment Station, made a survey on (1) the factors influencing erosion, (2) the extent and severity of erosion in the various parts of the State and (3) control measures (21).

The survey revealed :

(1) 13 per cent of the total land area shows little or no erosion ;
(2) 33 per cent shows slight sheet erosion with loss of up to 25 per cent of original surface soil ;
(3) 14 per cent has lost 25 to 50 per cent of its surface soil by erosion and shows occasional to moderate gullying ;

(4) 31 per cent has been seriously eroded, has lost 50 to 75 per cent of surface soil, and shows moderate to excessive gullies ;
(5) 9 per cent severely eroded, 75 per cent or more of surface soil lost, with moderate to excessive gullying.

Erosion is in the incipient stage on much Iowa land, and is not yet clearly evident. Preventive measures are essential to avoid a rapid increase.

The figures for the State of Missouri are quoted for comparison (28).

Type of erosion	Average amount of original surface soil washed away	Number of acres	Fraction of land area of the State
None to slight ..	0 to $\frac{1}{4}$	10,000,000	Slightly less than $\frac{1}{4}$
Moderate to serious ..	$\frac{1}{4}$ to $\frac{1}{2}$	12,000,000	Slightly more than $\frac{1}{4}$
Serious to severe ..	$\frac{1}{2}$ to $\frac{3}{4}$	20,000,000	Slightly less than $\frac{1}{2}$
Severe to excessive ..	over $\frac{3}{4}$	2,000,000	About $^1/_{20}$

Total land area of Missouri, 44,000,000 acres (approximately).

The conditions before the formation of the Leroy project, near Champaign-Urbana, Illinois, may be taken as an example of the type of agriculture which has led to these conditions. The area included in the project was 150,000 acres (recent projects do not generally exceed 25,000 acres) ; the land was ploughed to an excessive degree during the Great War and has been cropped with corn (maize) practically continuously. In one area of 150 farms, only 1 per cent of the land was under legumes. About 15 to 30 inches of the top soil have been removed in some areas. As in so many parts of the United States, it is the land tenure system which is chiefly to blame ; practically all the farmers are tenants, the rent for their farms (often not more than 100 acres in size) being on a crop share and a cash basis. The cash payment on the basis of the house, the buildings and the pasture land is about ten dollars per acre. The share-crop system is adopted for the land in crops and the farmer is therefore not encouraged to put land in pasture or clover. An economic study of this problem is discussed below.

Where erosion has not yet been severe in the Leroy project, rotations are being recommended, with or without terracing or strip cropping according to the situation ; special rotations are corn (maize), oats, clover or corn, corn, oats with annual sweet clover catch crop on the lower and better land.

The Iowa Report (21) recommends the usual cultural practices for controlling erosion in that State, combined with the adoption of a proper rotation which entails a reduction in corn acreage of 17 per cent. Limestone should be applied to acid soils to favour legume growth in the

rotation ; crop residues, green manure crops and farmyard manure are to be ploughed under ; phosphate and other fertilizers are to be applied to soils deficient in these constituents.

Miller (29) recommends standard rotations of one or two years corn (maize), one or two years small grain and one or two years clover, or clover and grass, for controlling erosion in Missouri. The one-year rotations of small grain crops and Korean lespedeza are also valuable. The Corn (maize) Belt States have seen a very considerable increase in the area under soybeans ; when these are grown in rows on rolling land, serious soil losses may occur, and drill sowing on the contour is advisable. Winter cover crops such as barley, rye, wheat, lespedeza, vetch and various clovers reduce erosion during the autumn, winter and spring.

The fact that the individual farmer is powerless in dealing with the erosion problem is stressed by Schickele, Himmel and Hurd (20), who state that erosion control is affeeted by economic and social forces beyond his control. These factors are listed briefly as follows :

Obstructive factors.	Facilitative factors.
1. Small farm size.	1. Large farm size.
2. Corn-hog type of farming.	2. Dairy and beef cattle type of farming.
3. Lack of supplementary enterprises.	3. Possibility of profitable supplementary enterprise.
4. Tenancy.	4. Owner-operatorship.
5. Short-term leases.	5. Long-term leases.
6. Crop-share leases.	6. Stock-share and cash-rent leases.
7. Tenant unrelated to landlord.	7. Tenant related to landlord.
8. Corporate landlord.	8. Private landlord.
9. Heavy debt burden and high interest rates.	9. Small debt burden and low interest rates.
10. Relatively low farm income level.	10. Relatively high farm income level.

A tenant-operator, in general, has no specific interest in keeping up soil fertility, as he is ready to move to another farm any time he sees fit. Tenancy has been on the increase since 1920, and is probably stimulating the rate of erosion. Short-term leases accentuate the general tenant attitude towards the soil, unless long tenure or security of tenure is given. The crop-share lease, the most common lease type, encourages crop cultivation, and particularly corn (maize) cultivation ; leases of this type usually run for one year only. Stock-share leases place the emphasis on live stock, particularly cattle, and on pasture and hay crops, and are usually long-term leases. The usual stock-share lease is not well adapted to dairy farmers, and an improvement in this direction would facilitate erosion control. A cash-rent lease affords the tenant complete freedom, provided the rent is adjusted to the price level.

Corporations are temporary land owners, having acquired the land by accident (usually, debt foreclosure), and are ready to sell as soon as a favourable offer is made. A tenant on corporate land has no assurance of staying on his farm for more than a year ; as soil conservation requires a long-time farming programme, the corporate landlord, in general, has little interest

in it. Almost half the tenant farms in this Survey of southern Iowa and northern Missouri are owned by corporations. A high proportion of land under such ownership tends to cause instability in land tenure and to foster erosion, unless the majority of corporations can be induced to adopt conservation programmes.

Great Plains

" During the past quarter of a century, dynamic ecology has come into wider opportunities of service in such well-established fields as forestry, agronomy and grazing, and has contributed steadily to the foundation of those more recently developed, such as erosion control and water supplies. With the present great expansion of federal projects has gone a corresponding utilization of ecological methods and concepts, even when this term has not been employed." (10).

In the study of conservation problems in the Western United States, namely, the Great Plains, the range country and the Pacific Coast, the ecological approach is of primary importance. The following review of the way in which the ecologist can help in solving the problems arising from over-grazing and improper land utilization is drawn (with extensive quotations) from Clements and Chaney (78).

In considering the past history of the West, no definite line need be drawn between the pioneers and the settlers, though their ecological relations were more or less different, especially in degree (Clements and Chaney, loc. cit.). By 1880 the true prairie of Kansas and Nebraska had been converted into farms, and cultivation was spreading steadily across the mixed prairie to the foothills of the Rockies.

According to Clements and Chaney the prairie at that time still possessed the cover which had characterized it since earlier post-glacial time. Tall grasses had shrunk back along the forest border and into the foothills, broad valleys and stretches of sand ; mid-grasses extended from the Mississippi Valley well beyond the Missouri and with an open undergrowth of short-grasses covered the plains from Saskatchewan to Texas. The Southwest (Region 8) was the home of the short-grasses and the Pacific Coast of the bunch-grasses of medium stature. Into this situation came the settler with his stock, to start the subsequent intentional or unwitting disturbances. The direct effect of breaking and cultivation was to destroy the prairie and loosen the soil, but indirectly it acted with the more immediate grazing, fire and haymaking to modify or transform the cover of grasses and forbs (35, 76 and 77). Owing to their climatic adjustment, the mid-grasses held their climax position with the ebb and flow of cycles, but confined grazing by herds or in pastures gave their competitors, the taller, coarser bluestems (*Andropogon* spp.) a small, but decisive superiority. Fire and haycutting were complementary factors, as were the grazing preference of cattle, the life-form (bunch-grass or sod-former) and the season of growth of the different species.

The story of the transformation of the mixed prairie is likewise one of victory of short-grasses over their taller associates. Farther west, in

the Californian prairie, the early contact with Spain brought in alien annuals such as wild oats, bromes and fescues, to take the place of the perennial bunch-grasses weakened by overgrazing. Similar signs of the interference of man and his animals with the balance between climax and climate elsewhere in the West are available in the conquest of grassland by weeds, sagebrush, creosote-bush and mesquite.

The supreme factor in the control of life in the prairie has been drought (Clements and Chaney, 78). Westward over prairie and plain, aridity is cumulative and droughts increase correspondingly in frequency ; their effects are most severe in the middle region, where they alternate sharply with adequate rainfall, and hence where compensation for them is most difficult.

Early attempts were made to apply the findings of ecology to the problems which arose as a result of mistaken zeal for settlement and utilization of the West. As early as 1898, all the essential features of the proper ecological system for the development of the Great Plains had been clearly set forth. Pound and Clements (35) emphasized the serious effects of disturbance of the soil by man and pointed out that breaking of sod and over-grazing were replacing the native perennial grasses by annual weeds and setting into action the regenerating processes of succession. It was insisted that most of the sandhills and tablelands were unsuited to cultivation and of value only for grazing purposes. Definite systems of range management were advanced between 1895 and 1899, and in 1901 the Federal regulation of grazing lands was suggested ; this recommendation was suppressed by the Secretary of Agriculture of the time and is only now being put into force (73). For the Great Plains, Shantz (57) developed the method of indicator plant communities to the point where it revealed clearly the possibilities of local climates and soils in terms of crop production and became the standard for purposes of land classification in the public domain. All these ecological principles were shortly after amplified and extended over the West, as described by Clements in " Plant Succession " (76) and particularly in "Plant Indicators" (77), which was a comprehensive and detailed account of the relations of plant communities to natural processes and cultural practices. These two books constitute the basis for the combined attack upon the problems of readjustment, with their insistent demand for solution through the Forest Service, Soil Conservation Service, Bureau of Plant Industry and Biological Survey. The major emphasis in both treatments rested upon the recognition of drought as the crucial factor in a dynamic system, by contrast with the application of incomplete and disconnected procedures.

Clements and Chaney state that recovery is to be understood in all its various meanings, but with the chief emphasis upon the restoration and improvement of the cover. To-day, man's influence is exerted almost universally upon some substitute community or proclimax, such as burnt-forest, short-grass sod or field of grain. The clue for recovery must therefore be sought in the cause for each type of proclimax and the process

which has brought it into existence and maintains it against the natural advantage of the climax. Succession is the natural process of recovery and in some form or other must remain the chief reliance of man in undoing the damage already done.

The range of choice is limited by the degree to which the climax has been modified or destroyed, and the economic considerations involved in restoration, as well as by preferences in the matter of ease. The western corn (maize) belt will not return to prairie by natural processes for centuries or even millenia, owing to the small and scattered relicts, while the abandoned dryland farms of Nebraska may be reabsorbed by the mixed prairie in five years. Where the displacement is only partial, as in the conversion of mixed prairie to short-grass by overgrazing, the restoration of the original cover by means of fencing is usually a simple and rapid process, but over the wide extent of the disclimax of annual grasses in California, natural recovery can now be only rare and local. Revegetation by planting and sowing is justifiable only where the valuable wild oats have been replaced by the much less desirable annual bromes and fescues.

As part of the huge programme of relief and rehabilitation inaugurated in the Great Plains as the result of the great drought in 1934, a proposal was made in June, 1934, to plant shelterbelts on about 1,000,000 acres of farm land within a zone 100 miles wide extending through the prairie-plains region from the Canadian border into the Texas Panhandle* (59). This project was commenced in the face of amazing misunderstandings on the part of the public at large, who were led to believe that a solid belt of trees, 1,000 miles long by 100 miles wide, was to be planted from Canada to Texas, either to abate the winds or increase the rainfall in the mid-western States (36).

It is recognized that shelterbelt development is only one phase of Plains management, a phase which must be developed in harmony with the entire land-use pattern of the region. Trees grouped together as windbreaks or shelterbelts are credited with the improvement of physical conditions, the protection of crops and crop land, but they are also of great value in improving the morale of the Plains dweller, by providing shade from glare, shelter from winds and so on.

The general effect of shelterbelts is not the creation of more rainfall over the area covered by tree growth but the more economic use and conservation of the available rainfall (60). Shelterbelt planting should be considered as part of a much broader programme of water conservation, erosion control, terracing, strip-cropping, etc. A special Great Plains forest experiment station to study various aspects of the problem, such as the effects of shelterbelts upon crop yields and physical factors, etc., has been authorised by Congress (1936).

Olson and Stoeckeler (59) tabulate an extensive list of species of value for shelterbelts and their adaptation to different soil types.

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*See also Canadian section for shelterbelt studies.

The U.S. Forest Service Report (58) represents a comprehensive study of all aspects of the problem, and will be of value to all concerned with shelterbelt planting in areas of semi-arid grasslands.

A special report has been published, entitled "The future of the Great Plains," and represents the most comprehensive treatment yet available for a conservation plan for a great region. Dr. F. E. Clements had much to do with the decision as to the future of the region; his opinions will be available in a forthcoming paper on "Climatic cycles and human population." Unfortunately, neither of these publications is available for summarizing at the time of writing.

Wind Erosion Region

The chief problem in the Great Plains Regions (Northwest No. 9 and Central No. 7, and particularly in the Southern Great Plains Wind Erosion Region No. 6) is the control of drifting and blowing of soil.* The control measures representing successive lines of defence against wind erosion are enumerated by Finnell (63) as follows, in the order of their relative importance.

1. Utilization of erosion-resisting crop residues.
2. Moisture conservation for maintenance of vegetation.
3. Emergency cover crops.
4. Windbreak tree planting.
5. Emergency tillage operations.

Crops which give erosion-resisting residues include wheat, barley, oats and rye; row crops which give erosion-resisting residues include the grain and forage sorghums. The ideal system of management would require that the vegetative cover is not disposed of until soil moisture sufficient to ensure the successful start of the next crop has been accumulated in the soil. Some of the worst cases of wind erosion are due to the burning of stubbles and the overgrazing of stalk fields.

Terracing and contour tillage have been shown capable of increasing the average soil moisture supply by about 25 per cent under High Plains conditions on heavy soils and have become a very material support to the vegetative programme. Contour and basin listing are also valuable practices. Contour furrowing on pasture and range lands has a marked effect on the moisture relations of the soil and the composition of the grassland (32). Much can be done in the direction of flood irrigation by using water collected in storage reservoirs, diversion dams, contour dikes and ditches (30 and 23). Similar methods can be used in collecting water for stock.

Cultivation methods should have as their objectives the ridging or clodding of the surface soil and the raising of heavy subsoil material to the surface. Special implements are used for this purpose.

The reconditioning of lands damaged by wind erosion depends upon

*See also Canadian section.

the extent of the damage. In some cases, suitable cultivation methods may be used for a given period, in order to restore the moisture to the soil, before a crop can be grown. Seriously drifted areas may have to be restored to grass by sodding or seeding, if this is still possible. Abandoned, drifted fields will revert to grassland slowly, first developing a cover of Russian thistles (*Salsola pestifer*), followed by annual weeds and grasses, and finally by perennial grasses.

A popular article by Hibbs (19) gives a clear picture of the conditions in the Dust Bowl area some years ago, the rather exaggerated and pessimistic statements which were then made regarding the possibilities of reclaiming the area, and the very striking results which have been obtained in recent years. One particular experiment, in charge of C. J. Whitfield, in the stabilization of sand dunes which had reached a height of 20 to 30 ft. a few years ago, may be quoted. These dunes were " blown down " in the following way. The lands in the vicinity of the dunes were anchored by hardy drought-resistant cover crops, thus cutting off the source of supply. During the winter and spring seasons of high winds, the tops and slopes of the ridges were left exposed and loosened with tillage implements. Every day the wind scoured off the sand and deposited it in a thin layer in the surrounding stubble. During the growing season a crop was planted on the dunes to protect the adjacent areas of maize. This process is repeated each season, and it is expected that finally this 900-acre tract will be level and growing good crops of milo, Sudan grass, black amber cane, broom corn and other row crops, the stubble of which prevents wind erosion during winter and spring.

Two studies of the soils of the southern High Plains may be mentioned. Daniel (12) made mechanical analyses of cropped and virgin surface and sub-surface soils and compared them with the sand, silt and clay contents of the soil drifts. The greatest difference between drift material and the cropped and virgin surfaces occurred in the coarse and medium-textured types. The drifts contained an average of 37.8 per cent less silt and clay, and 29.3 per cent more sand than the adjacent virgin soil. The increase in percentage of sand in the drifts was in proportion to the amount of silt and clay removed by wind. The drift from the coarse-textured soils had the highest clay ratios and the clay soils the lowest ; it is considered that there is little relation between the clay ratio and wind erosion.

Daniel and Langham (13) also determined the total nitrogen and organic matter content in cropped, virgin and drifted soils. Each time a soil is shifted, more plant nutrients are removed ; finally, the dunes from soils dispersed by wind become sand, regardless of the original texture. The organic matter-nitrogen ratios were : cropped soil—22.47 ; virgin soil —23.30 ; drifts—24.44. Since the total nitrogen and organic matter decrease rapidly with depth, the data prove the necessity of retaining the surface soil. As a result of cropping and wind erosion, the organic matter in the cultivated soils was decreased by 18 per cent and the nitrogen by 15 per cent. Very little difference occurred in the nitrogen and organic matter content of the cropped and virgin sub-surface soils.

The Western Range

In the programme of research and demonstration on range lands, the Soil Conservation Service and the Forest Service work in co-ordination. With regard to research, the former is primarily responsible for erosion studies on agricultural lands, the Forest Service on forest and range lands. Any project proposed by either agency which closely relates to the work of the other is first reviewed by the other agency and then by a co-ordinating Committee. The Forest Service keeps in close touch with the field studies of the SCS and vice versa. As to erosion control operations, the Forest Service is responsible for advice to farmers and others in designating the practices applicable on forest and range lands, the SCS on agricultural lands, including farm pastures. All erosion control within approved project areas of the SCS is under its direct control. These demonstration projects also include certain Indian Reservations and certain public lands, which include range lands. Within the national forests the Forest Service is responsible for all erosion control.

The restoration of depleted range lands is described in "The Western Range" (61) and by Chapline (8 and 9).

The native forage-producing lands in the United States suitable for use by live-stock cover a total of 728 million acres, or about 38 per cent of its area. This range country lies in the western half of the United States and consists almost exclusively of lands which are unsuitable for any other form of agriculture because of the relatively meagre precipitation or other adverse climatic conditions, rough topography, or lack of water for irrigation. Within this range territory 19 million cattle and 36 million sheep and goats graze for part or all the year and produce 75 per cent of the country's total production of wool and mohair, 55 per cent of the sheep and lambs and nearly one-third of the cattle and calves. Owing to the low precipitation (averaging 15 inches per annum), high evaporation and other adverse factors, range forage production is small, as compared with that of humid pastures. On the best of range lands two acres are required to support a cow for a month, while on the poorest, 20 or more acres may be required. In addition, recurring drought makes sustained forage production uncertain, requiring still more conservative grazing.

To the pioneer stockman the range offered a great adventure, ambition, dreams of wealth, a home, and possibly a cattle kingdom. For a time, vast live stock investments were made from the Eastern States and even from foreign countries. More settlers poured into the range territory and competition became acute. Wars between cattlemen and sheepmen and between stockmen and the farmer-homesteader caused the destruction of herds and the loss of human lives. Life in the range country was hard. Few of the pioneers had the advantage of wealth or education and the early stockmen developed a rule-of-thumb system of range practice, which generally failed to take account of all the difficulties inherent in the preservation of range.

Through overstocking in the short space of 50 years much of the

grazing value of the range has been seriously depleted and even now stockmen are attempting to graze approximately 17 million animal units on range having a sustained grazing capacity of about 10 or 11 million units. All but two of the principal range types are depleted by half or more. The tall-grass range depleted by only 21 per cent reflects especially favourable growth conditions. The open forest type, with depletion of about 33 per cent, also reflects favourable climatic conditions and national forest management. The salt-desert shrub, southern desert shrub, and sagebrush-grass types all reflect critical growing conditions and loss of grasses from excessive grazing.

An important factor in depletion has been the unsound land policy under which 100 million acres or more of submarginal land have passed to private ownership, regardless of character, much to be cultivated unwisely. The successive waves of failures, reduced standards of living, the defeat of hopes and ambitions, the abandonment of homes, closed schools and churches, widespread tax delinquency and large acreages reverted to counties and States, furnish an indication of the effect of unrestrained exploitation and range destruction on social well-being.

The magnitude of the range land problems is now recognized with all its implications in land ownership, in public and private land administration, management and control, in the better integration of range and crop agriculture, and finally in expanded programmes for research and education.

Sustained management stands out prominently in the programme of restoration. This requires the stocking of each range with the proper number and class of live stock for a suitable season or seasons, and the obtaining of such handling and distribution as will ensure uniform and satisfactory use of all the forage. Improvements, such as fences, which aid in control of live stock, improved watering places and adequate distribution of salt are of importance. The 20 per cent improvement in grazing capacity resulting from the application of such management within the national forests has demonstrated the value of the research and the possibility of obtaining better resource, social and economic conditions generally.

The passage of the Taylor Grazing Act on June 28, 1934, marked the culmination of years of effort to obtain from Congress express authority for Federal regulation of grazing on the public domain in the interests of national conservation and of the live stock industry (73). It authorizes the Secretary of the Interior to provide for the protection, orderly use, and regulation of the public ranges, and to create grazing districts with an aggregate area of not more than 80 million acres. It confers broad powers on the Secretary of the Interior to do everything necessary for the preservation of these ranges, including the right to specify from time to time the number of live stock which may graze within such districts and the seasons when they shall be permitted to do so. This authority is carefully safeguarded against interference by State or local action. Creation of a grazing district by the Secretary of the Interior will supersede State regulation of

grazing in that part of the public domain included within such a district. Wider development, soil erosion work and the general improvement of such lands are provided for in the Act.

Local residents, settlers and owners of land and water who have been using the public range in the past are given preference in the use of lands within such districts when placed under Federal regulation. The Act permits private persons owning lands within a district to make exchanges for Federally owned land outside a grazing district, if and when the Secretary of the Interior finds it to be in the best public interests. A special Administration has been organized in the Department of the Interior to carry out the provisions of this Act.

South-Western States

Extensive erosion-control and land-management programmes are being carried out by the SCS in the South-West (Region 8), in co-operation with the Forest Service, the Indian Service and the Taylor Grazing Act Administration. These projects are (1) the Navajo Indian Reservation of 17 million acres in New Mexico and Arizona, (2) the upper Gila river watershed, including the San Pedro and Santa Cruz tributaries comprising about 14 million acres in New Mexico and Arizona, (3) the Rio Grande watershed above Elephant Butte Reservoir, embracing over 14 million acres in New Mexico. Material progress has been made in the development of sound land-use schemes permitting the users of Indian land to carry on operations without shifts. Water spreading by the construction of extensive dams with spillways, and range revegetation are now the chief lines of operation.

According to the Report of the Regional Conservator (68) reductions in live stock have been made as follows in Region 8 (Utah, Colorado, New Mexico and Arizona) :

(1) 37 per cent on 727,664 acres in the Rio Grande District;
(2) 24 per cent in the Gila District ;
(3) 17 per cent in five Utah areas ;
(4) from 1934 to 1937 the reduction in the Navajo Reservation has been about 28 per cent.

Stock and range management on the work areas resulted in higher yields of meat and wool per unit of stock ; the wool obtained a higher price owing to its superior quality. The lambing rate was higher, and lambs were heavier at marketing time.

Soil Conservation Districts

Since January 1, 1937, the legislatures of twenty-two States have passed laws providing for the creation of soil conservation districts, a movement which, as already described, started in Alabama and Georgia. Bills providing for similar laws are being considered for introduction in other States. The

Department of Agriculture, co-operating with the States, welcomes this opportunity to work with the 6 million farmers and ranchers who control the use of most of the arable land in the United States, through these co-operating groups which the soil conservation district laws permit them to organize (69 and 62).

These laws are enabling acts which permit farmers to organize and form soil conservation districts which will have the status of governmental sub-divisions of the State. Whether a district is formed rests entirely with the farmers. The powers granted to a district are of two kinds. After a district is formed and granted a certificate of organization from the State, farmers then have authority (1) to engage in co-operative action to combat erosion, and (2) to prevent local misuse of land by voting land-use regulations upon themselves, similar to the ordinances which every city, town or county may adopt (e.g. town-building, etc.). All land-use ordinances must be submitted to a referendum and publicly approved before they can be given effect. As examples are quoted regulations which may be adopted in dust country to require contour listing of all blowing land that is a danger to other lands, or in humid country to require the retirement of certain badly eroded hillsides to trees or grass to protect fields below.

The administrative officers of a district are directed by a board of three to five supervisors or directors, local residents who serve unpaid for three years. Each district is independent, not subject to the control of the State soil conservation committee or any other agency, once its boundaries are determined and operations have begun.

The functions of the State soil conservation committee, which also is created by the laws, are to make the legal determinations necessary in connexion with creating a district, to encourage the organization of districts and define their boundaries, to bring about an exchange of information and experiences among the districts in the State and to co-ordinate as far as possible the several district programmes. These committees usually contain five members, such as the director of the State agricultural extension service, the director of the State agricultural experiment station, and the administrative heads of other State agricultural agencies.

The work undertaken by the districts may be financed in several ways; (1) the landowner and land-operator who benefit directly from the application of erosion-control measures to their lands may bear a share of the expense, furnishing labour, materials, equipment, etc.; (2) the State and Federal Governments may also bear a share. Appropriations may be made available out of funds in the State treasury and allocated by the State soil conservation committee, and services, funds, and properties may be contributed by the United States through the Department of Agriculture or other agencies.

The SCS is now devoting particular attention to the development of these new soil conservation districts. New projects (see page 132) are not now being commenced, as districts are coming forward rapidly, and some

are already in actual operation. Possibly in a few years the Service will be working entirely on a district basis.

* * * * *

Space does not permit of a full consideration of the numerous nation-wide aspects related to the conservation programme, such as erosion and flood control and the use of the headwater and other small streams (34, 66 and 67); wildlife and erosion control (64 and 65); the plants valuable for wildlife utilization (49); the silting of reservoirs (52) and erosion control on mountain roads (48).

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Appendix to
U.S.A. Section

UNITED STATES

DEPARTMENT OF AGRICULTURE

SOIL CONSERVATION SERVICE

COOPERATIVE AGREEMENT

AGREEMENT FOR DEMONSTRATIONAL AND EXPERIMENTAL WORK IN SOIL AND WATER CONSERVATION

THIS AGREEMENT, entered into this.....day of..... 19.., by the United States of America, by the.....Manager, hereinafter called the Government, and

.....	.....	.....	.....	.....
(Last name)	(PRINT)	(First name)	(City)	(State)
.....	.....	.....	.....	.....
(Last name)	(PRINT)	(First name)	(City)	(State)
.....	.....	.....	.....	.....
(Last name)	(PRINT)	(First name)	(City)	(State)
.....	.....	.....	.....	.....
(Last name)	(PRINT)	(First name)	(City)	(State)
.....	.....	.....	.....	.....
(Last name)	(PRINT)	(First name)	(City)	(State)

hereinafter called the Cooperator(s) :

WITNESSETH, that the parties hereto do mutually agree as follows :

ARTICLE 1. The officer in charge shall be the.....Manager, hereinafter called the officer in charge.

ARTICLE 2. The Government agrees to make the essential surveys for use in developing a suitable plan of soil and water conservation, and to assist in formulating a plan of conservation operations.

ARTICLE 3. The Cooperator(s) agrees to follow the plan of conservation operations attached hereto, in accordance with the directions and under the guidance of the officer in charge or his duly authorized representatives, insofar as the officer in charge may find it necessary for the purposes of soil and water conservation.

ARTICLE 4. For a period of 5 years from the date of this agreement the Cooperator(s) agrees to continue all farming, grazing, wild-life, and forestry practices required by this agreement and to maintain all fences, terraces, and other structures erected pursuant thereto, in a condition and in a manner satisfactory to the officer in charge.

ARTICLE 5. The Cooperator(s) agrees to furnish material, equipment, and labor as specified in the plan of conservation operations, attached hereto.

ARTICLE 6. It is stipulated that planting stock and materials furnished by the Government shall not be sold or disposed of by the Cooperator(s).

ARTICLE 7. The Cooperator(s) agrees to protect, to the best of his ability, from fire, all wooded and other areas not used for farm crops.

ARTICLE 8. The Government agrees to build the necessary structures and devices which it may deem necessary and practical in special cases to prevent damage from uncontrolled waters entering upon the farm from neighbouring lands.

ARTICLE 9. In order that the Government may direct and supervise the work, the farming, grazing, wild-life, and forestry practices undertaken in this Agreement, the Cooperator(s) shall allow the officer in charge and/or his duly authorized agents free access to any of the lands involved during the period of this agreement.

ARTICLE 10. In the event that Cooperator(s) fails to fulfil his undertaking in a satisfactory manner, the parties agree that the Government may terminate this agreement and shall be entitled to recover as liquidated damages the cost of materials (but not equipment) used by the Government, under this agreement.

ARTICLE 11. The Cooperator(s) agrees that the Government shall not be liable for any injury to person or property incurred in connection with the prosecution of the work under this agreement.

ARTICLE 12. In consideration of the benefits to be derived from the establishment of the erosion-control practices adopted on the land, the landlord/tenant agrees to be bound by the terms of this agreement as though he were named as the Cooperator(s).

ARTICLE 13. If at any time a party hereto shall cease to have any legal relationship (whether as landlord or tenant) to the land described on the map attached hereto and incorporated as part of the agreement, this contract shall become inoperative and of no further force or effect as to such party.

ARTICLE 14. In event present or future farm legislation interferes with the cropping plan of this agreement, the needed changes may be made subject to the approval of the officer in charge.

ARTICLE 15. The site of the work, with land description plan of conservation operations, cropping plan and map attached hereto, are incorporated as part of the agreement.

ARTICLE 16. No Member of or Delegate to Congress or Resident Commissioner shall be admitted to any share or part of this contract or to any benefit that may arise herefrom, but this restriction shall not be construed to extend to this contract if made with a corporation or company for its general benefit.

The parties hereunto have executed this agreement, the United States of America by the contracting officer, and the Cooperator(s) has hereunto signed his name, the day and year hereinabove written.

THE UNITED STATES OF AMERICA.

.....

.....*Manager.*

....
Cooperator. (Title—owner or operator)

....
Cooperator. (Title—owner or operator)

....
Cooperator. (Title—owner or operator)

....
Cooperator. (Title—owner or operator)

....
Cooperator. (Title—owner or operator)

WITNESS :

.....

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.....
Contracting Officer.

References (United States of America)

1. Ayres, Q. C. Soil erosion and its control. 24 × 16. pp. xi + 365. London and New York: McGraw-Hill Publ. Co. Ltd., 1936.
2. Barbour, G. B. The Tennessee Valley Project. *Geogr. J.* **89.** 393-408. 1937.
3. Baver, L. D. Some soil factors affecting erosion. *Agric. Engng. St. Joseph, Mich.* **14.** 51-2 and 57. 1933.
4. Bennett, H. H. Some comparisons of the properties of humid and humid-temperate American soils with special reference to indicated relations between chemical composition and physical properties. *Soil Sci.* **21.** 349-75. 1926.
5. Bouyoucos, G. J. The clay ratio as a criterion of susceptibility of soils to erosion. *J. Amer. Soc. Agron.* **27.** 738-41. 1935.
6. Brown, B. A. The effects of fertilizers on the soil, the botanical and chemical composition of the herbage and the seasonal and total production of grassland in Connecticut. Einflüsse der Düngung auf den Boden, die botanische und chemische Zusammensetzung der Gräser und die saisonmässige bezw. Gesamtproduktion auf Grünland in Connecticut (USA). *Rep. Fourth Int. Grassl. Congr. Gt. Brit.* 1937. Sectional Session 4. 313-7. [German summary, 316-7. Discussion, 317.] Aberystwyth, 1937.
7. Brown, G. Spreading water in the east. *Soil Conserv.* **2.** 143 and 145. 1937.
8. Chapline, W. R. Range research in the United States. *Herb. Rev.* **5.** 1-13. 1937.
9. ———————— Restoring range lands in the United States. Verbesserung früherer Weideflächen in U.S.A. *Rep. Fourth Int. Grassl. Congr. Gt. Brit.* 1937. Sectional Session 1. 124-31. [German summary, 128, Discussion, 129-31.] Aberystwyth, 1937.
10. Clements, F. E. Experimental ecology in the public service. *Ecology.* **16.** 342-63. 1935.
11. Dahl, A. S. Progress report on contour furrowing in the corn belt. *Soil Conserv.* **2.** 141-2 and 145. 1937.
12. Daniel, H. A. The physical changes in soils of the southern high plains due to cropping and wind erosion and the relation between the $\frac{\text{sand} + \text{silt}}{\text{clay}}$ ratios in these soils. *J. Amer. Soc. Agron.* **28.** 570-80. 1936.
13. ————————, and Langham, W. H. The effect of wind erosion and cultivation on the total nitrogen and organic matter content of soils in the Southern High Plains. *J. Amer. Soc. Agron.* **28.** 587-96. 1936.
14. Detwiler, S. B. Slope usage. *Soil Conserv.* **3.** 64, 66-7 and 83. 1937.
15. Dodge, A. F. Measurement of run-off as influenced by plant cover density. *Iowa St. Coll. J. Sci.* **9.** 399-407. 1935.
16. Duley, F. L., and Hays, O. E. The effect of the degree of slope on run-off and soil erosion. *J. agric. Res.* **45.** 349-60. 1932.
17. ————————, and Ackerman, F. G. Run-off and erosion from plots of different lengths. *J. agric. Res.* **48.** 505-10. 1934.
18. Herbage Reviews. Wind erosion in the Southern Great Plains. *Herb. Rev.* **5.** 106-7. 1937. [Review by R. M. Whyte of U.S. Dept. Agric., Soil Cons. Serv., Tech. Bull. No. 556. By A. H. Joel, 1937. pp. 68.]
19. Hibbs, B. The Dust Bowl can be saved. *Saturday Evening Post.* **210.** 16-7, 77-8 and 80-2. 1937.
20. Iowa Agricultural Experiment Station. Bull. No. 333. Economic phases of erosion control in Southern Iowa and Northern Missouri. By R. Schickele, J. P. Himmel and R. M. Hurd. 1935. pp. 189-232.

21. ————————————————, and U.S. Department of Agriculture, Soil Conservation Service, co-operating. Spec. Rept. No. 2. Soil erosion in Iowa. By R. H. Walker and P.E. Brown. 1936. pp. 47. Map.
22. Johnstone-Wallace, D. B. The influence of wild white clover on the seasonal production and chemical composition of pasture herbage, and upon soil temperature, soil moisture, and erosion control. Der Einfluss des wilden Weissklees auf die jahreszeitliche Erzeugung, auf die chemische Zusammensetzung des Weideertrages und auf den Boden. *Rep. Fourth Int. Grassl. Congr. Gt. Brit.* 1937. Sectional Session 2. 188-96. [German summary, 195-6. Discussion, 196.] Aberystwyth, 1937.
23. Lewis, M. R. Water conservation and supplementary irrigation in the northern Great Plains. *Agric. Engng. St. Joseph, Mich.* **18.** 495-6. 1937.
24. Lowdermilk, W. C. Soil erosion and its control in the United States. *Trans. 3rd Internat. Congr. Soil Sci.* **2.** 181-94. 1935.
25. ———————— Ecological principles. *Soil Conserv.* **3.** 54 and 59. 1937.
26. McGrew, P. C. Mechanical methods of water conservation on pasture and range land. *Agric. Engng. St. Joseph, Mich.* **18.** 487-8 and 491. 1937.
27. McIntyre, A. C. Trees and erosion control. *Bull. Amer. Soil Surv. Ass.* **16.** 110-4. 1935.
28. Missouri Agricultural Experiment Station. Bull. 349. Soil erosion in Missouri. By L. D. Baver. 1935. pp. 66.
29. ———————————— Bull. 366. Cropping systems in relation to erosion control. By M. F. Miller. 1936. pp. 36.
30. Montana Agricultural Experiment Station. Bull. 301. Conservation of water by means of storage reservoirs, diversion dams, contour dikes and ditches. By O. W. Monson. 1935. pp. 48.
31. Musgrave, G. W. A quantitative study of certain factors affecting soil and water losses as the logical basis for developing practical methods of erosion control. *Trans. Amer. geophys. Un.* 1934. 515-21.
32. Newport, F. C. A corduroy coat protects High Plains from drought. *Soil Conserv.* **2.** 139-40 and 145. 1937.
33. Parkins, A. E., and Whitaker, J. R. Our natural resources and their conservation. 23 × 16. pp. 662. New York and London : Chapman and Hall. 1936.
34. Person, H. S. Little waters. A study of headwater streams and other little waters, their use and relations to the land. By H. S. Person with the co-operation of E. Johnston Coil and R. T. Beall, for Soil Conservation Service. Revised edition. Washington, 1936. pp. 82. pls. charts.
35. Pound, R., and Clements, F. E. The phytogeography of Nebraska. 1898. 2nd ed. 1900.
36. Rechel, Z. C. Streamlining America's plains by proper planting. Government Foresters are building a green shelter-belt which gives promise of success in combating wind erosion such as threatened to turn farmland into desert. *Christian Sci. Monitor.* 1937. Nov. 3. p. 6.
37. Sears, P. B. Deserts on the march. Norman : University of Oklahoma Press 1935. pp. 231.
38. Semple, A. T. Following contour furrows across the United States. *Soil Conserv.* **2.** 134-8 and 145. 1937.
39. United States, Congress. Act (Public-No. 46—74th Congress) (H.R. 7054). To provide for the protection of land resources against soil erosion, and for other purposes. [Washington] 1935. pp. 2. [Mimeographed.]
40. ————————, Department of Agriculture. Fmrs.' Bull. No. 1234. Gullies ; how to control and reclaim them. By C. E. Ramser. Washington, 1922. Revised 1935. pp. 34.

41. ———— Fmrs.' Bull. No. 1475. Soil productivity as affected by crop rotation. By W. W. Weir. 1926. pp. 22.
42. ———— Fmrs.' Bull. No. 1628. Growing black locust trees. By W. R. Mattoon. 1930. pp. 13.
43. ———— Tech. Bull. 178. Properties of soils which influence erosion. By H. E. Middleton. 1930. pp. 16.
44. ———— Tech. Bull. 232. A laboratory study of the field percolation rates of soils. By C. S. Slater and H. G. Byers. 1931. pp. 23.
45. ———— Fmrs' Bull. 1697. Using soil-binding plants to reclaim gullies in the south. By H. G. Meginnis. 1933. pp. 17.
46. ———— Tech. Bull. 430. The physical and chemical characteristics of the soils from the erosion experiment stations. Second report. By H. E. Middleton, C. S. Slater and H. G. Byers. 1934. pp. 62.
47. ———— Misc. Publ. No. 196. Floods and accelerated erosion in northern Utah. By R. W. Bailey, C. L. Forsling and R. J. Becraft. 1934. pp. 21.
48. ———— Circ. No. 380. Erosion control on mountain roads. By C. J. Kraebel. 1936. pp. 45.
49. ———— Circ. No. 412. Groups of plants valuable for wildlife utilization and erosion control. By W. L. McAtee. 1936. pp. 11.
50. ———— Fmrs.' Bull. 1758. Cover crops for soil conservation. By W. V. Kell and R. McKee. 1936. pp. 14.
51. ———— Misc. Publ. No. 233. List of technical workers in the Department of Agriculture and outline of Department functions. 1935. Washington, 1936. pp. 132.
52. ———— Tech. Bull. 524. Silting of reservoirs. By H. M. Eakin. 1936. pp. 141.
53. ———— Fmrs.' Bull. 1767. Soil defence in the Piedmont. By E. M. Rowalt. In collaboration with Subject-matter Specialists of the Soil Conservation Service. 1937. pp. 62.
54. ———— Fmrs.' Bull. 1776. Strip cropping for soil conservation. By W. V. Kell and G. F. Brown. 1937. pp. 37.
55. ———— Fmrs.' Bull. 1790. The Nichols terrace : an improved channel-type terrace for the south east. By J. J. Henry and M. L. Nichols. 1937. pp. 12.
56. ———— Tech. Bull. 558. Soil and water conservation investigations at the Soil Conservation Experiment Station, Missouri Valley Loess Region, Clarinda, Iowa. Progress report, 1931-35. By G. W. Musgrave and R. A. Norton. 1937. pp. 181. charts.
57. ————, Bureau of Plant Industry. Bull. 201. Natural vegetation as an indicator of the capabilities of land for crop production in the Great Plains area. By H. L. Shantz. 1911. pp. 100.
58. ————, Forest Service. Possibilities of shelterbelt planting in the Plains region. 29 × 23. pp. 201. Washington : Govt. Printing Office, 1935.
59. ———— Possibilities of shelterbelt planting in the Plains region. Sect. 4. The proposed tree plantations—their establishment and management. By D. S. Olson and J. H. Stoeckeler. 1935. pp. 15-27.

60. ———— Possibilities of shelterbelt planting in the Plains region. Sect. 6. Prospective effects of the tree-planting program. By R. Zon. 1935. pp. 33-8.

61. ———— 74th Congress. 2nd Session. Doc. No. 199. The Western Range. Letter from the Secretary of Agriculture transmitting in response to senate resolution No. 289 a report on the Western Range— a great but neglected natural resource. 1936. 23 × 15. pp. 636.

62. ————, Soil Conservation Service. A standard State Soil Conservation Districts Law. Prepared at the suggestion of representatives of a number of States. 1936. pp. 64.

63. ———— Prevention and control of wind erosion of high plains soils in the Panhandle area. By H. H. Finnell. 1936. pp. 13. [Mimeographed.]

64. ———— Wildlife management by the Soil Conservation Service. By E. G. Holt. SCS-MP-5. 1936. 5. [A paper presented before the North American Wildlife Conference, Washington, D.C.]

65. ———— Wildlife and erosion control. By H. H. Bennett. SCS-MP-9. 1936. 13. [An address presented before the Annual Convention of the National Association of Audubon Societies New York, N.Y. October 29, 1935.]

66. ———— Soil conservation and flood control. By H. H. Bennett. SCS-MP-11. 1936. 14. [An address given before the Connecticut Engineering Congress, Bridgeport, Connecticut, July 25, 1936.]

67. ———— The arrest and prevention of devastation by floods. By G. L. Fuller and H. M. Eakin. SCS-MP-12. 1936. 11. [Given before the Connecticut Engineering Congress, Bridgeport, Connecticut, July 25, 1936.]

68. ———— Annual Report. Region No. 8. Fiscal year 1936-1937. (New Mexico, Arizona, Utah, Colorado.) By H. G. Calkins. [Washington] 1937. pp. 220. [Mimeographed.]

69. ———— Misc. Publ. No. 293. Soil conservation districts for erosion control. 1937. pp. 19.

70. ———— Soil and water conservation investigations. Progress report, 1931-35. Pacific Northwest Soil Conservation Experiment Station, Pullman, Wash. By P. C. McGrew and G. M. Horner. SCS-ESR-2. 1937. 123. Tables. [Mimeographed.]

71. ———— Soil and water conservation investigations. Progress report, 1930-35. Red Plains Soil Conservation Experiment Station, Guthrie, Okla. By H. O. Hill, H. M. Elwell and J. W. Slosser. SCS-ESR-3. 1937. pp. 41. Tables. [Mimeographed.]

72. ———— Provisional problem areas in soil conservation research in the United States. [Map] R-1890. 1937. 78 × 60. [Revised from map prepared for Joint Symposium, Sections V and VI, Soil Sci. Soc. America, Nov. 1936.]

73. ————, Department of the Interior. Taylor Grazing Act (Approved June 28, 1934, Public No. 482), Washington, 1934. pp. 16. [Including Statement of the President on approval of the act, explanation of the law and text of the act.]

74. ————————, National Resources Board. A report on national planning and public works in relation to natural resources and including land use and water resources, with finding and recommendations. Part II. Report of the Land Planning Committee. 29 × 24. 89-251. Washington, 1934.
75. Utz, E. J. Some ABC's of soil conservation. *Soil. Conserv.* **1.** 1. 1936.
76. Washington, Carnegie Institution. Publ. No. 242. Plant succession. By F. E. Clements. Washington, 1916.
77. ———————————— Publ. No. 290. Plant indicators. By F. E. Clements. Washington, 1920.
78. ———————————— Suppl. Pub. No. 24. Environment and life in the Great Plains. By F. E. Clements and R. W. Chaney. Washington, 1936. pp. 54.

Canada

EASTERN CANADA

Although the greatest problem as far as Canada is concerned is wind erosion in the prairie provinces, water erosion is certainly a serious factor in impairing the productivity of the soil in Eastern Canada and in certain parts of the West. This is particularly true in regions where the topography is uneven and where a considerable proportion of the land is under cereal or more particularly row crops. Practically no attention is devoted by farmers to soil conservation practices such as strip cropping, diversion ditches and terraces (1).

Erosion in this part of Canada does not appear to have been recognized as a serious problem, although flooding along water courses in the spring is frequently blamed on deforestation.

PRAIRIE PROVINCES

The three Prairie Provinces comprise the most important area of field crops in Canada. In these provinces in 1934 there was a combined total of 38,701,720 acres under field crops, or 69 per cent of the entire area of field crops in Canada. When it is considered that approximately 8,457,000 acres of cropped land were affected by drought and soil drifting in these provinces in 1934 and that the yield of wheat in this affected area averaged less than five bushels per acre, the extent and severity of the drought and soil drifting will be realized (4).

Reference is made to the occurrence of soil drifting in the prairie provinces in some of the earliest reports of the Dominion Experimental Farms. In 1887 severe drifting was experienced at Indian Head, Saskatchewan, and throughout that district. Soil drifting is, therefore, not of recent origin, but appears to have developed soon after the prairie lands were broken and seeded to grain. About 1918 determined efforts to control drifting were commenced in the Monarch district in Southern Alberta. These efforts were so successful that the district is now regarded as the most outstanding example of successful control, even in an area where severe drifting is liable to occur almost every year. More recently, similar methods have been adopted in other districts, chiefly as a result of united action by groups of farmers. Over the greater part of the Prairie Provinces, however, the intermittent occurrence of drifting from year to year and the more or less widely separated areas involved have probably discouraged any extensive attack on the problem. During the years from 1931-1934 soil drifting became so serious and widespread that more definite action towards effective and permanent control became imperative (4 and 13).

Few areas on the prairie are entirely immune from soil drifting. The

practice of summer fallowing, essential over the greater part of the prairie for the conservation of moisture, provides large areas of bare land which are susceptible to drifting.

Acreages in crop, summer fallow and new breaking in the Prairie Provinces and Canada, 1936

Crop	Manitoba	Saskatchewan	Alberta	Three Prairie Provinces	Total six other Provinces	Total all Canada
	Thousand acres	Thousand acres	Thousand acres	Thousand acres	Thousand acres	Thousand acres
Wheat	2,566	14,596	7,360	24,522	767	25,289
Oats	1,441	4,610	2,454	8,505	4,613	13,118
Barley	1,384	1,299	1,036	3,719	713	4,432
Rye	93	326	151	571	63	635
Flax	88	354	17	459	8	467
Mixed grains	10	18	21	50	1,120	1,171
Hay and clover	365	230	367	962	7,824	8,786
Alfalfa	29	19	75	124	729	853
Corn	35	6	3	45	527	572
Potatoes	31	44	27	103	392	496
Roots	3	1	20	25	212	237
Other crops	7		1	9	195	205
New breaking	56	159	257	472		472
Summer-fallow	1,173	8,205	4,272	14,251	189	14,441
Total acreage under cultivation	7,283	29,871	16,066	53,821	17,358	71,190

(Provincial Reports and Canada Year Book.)

Observations indicate that extremely light and extremely heavy soils, such as sands and clays, are more susceptible to drifting than loams. The finer eroded particles are usually lifted very high into the air, indicating a turbulence in the wind, and it has been observed (4) that soil drifting often originates at focal points on the tops of ridges, from which it spreads rapidly. This phenomenon may be associated with the occurrence of lighter soil at the focal points. Southern Alberta, southern Saskatchewan and south-western Manitoba are the areas most susceptible, elsewhere there may be periods of several years between the occurrence of severe dust storms. Drifting usually occurs during the spring months of April and May, and occasionally during June, although it is not infrequent in southern Alberta even during the winter months.

In addition to the damage to arable lands, there is considerable overgrazing in the ranching areas, although they are in general better preserved than in the United States. It is, however, probably true to say that overgrazing on the prairie has not been sufficiently severe to result in erosion except in certain sandy areas (see page 181).

Causes of Soil Drifting

The fundamental causes have received very little scientific study. Most observers are agreed that newly-broken virgin soil seldom drifts, owing to the binding effect of the fibrous root material of the original vegetation. As in course of time this fibrous material decomposes, the soil loses its soddy condition and becomes susceptible to drifting. Cultivation of the soil expedites the destruction of the sod in newly-broken land and thereby contributes materially in promoting a soil condition susceptible to drifting. This is true also of summer-fallow land ; while clean cultivation is essential for weed control, it may promote drifting if not properly done.

There is some divergence of opinion with regard to the effect of humus. Many workers assume that its presence must be beneficial in maintaining soil structure, but it is an undecided point how far humus preserves structural stability in the *dry* state. The gradual depletion of humus by continued cultivation will, however, tend to break down the wet, and consequently also the dry structure (11). Moss (12) has shown that the high humus content of Saskatchewan black soils gave them no advantage over less humus-rich soils. He showed furthermore that the drifts of clay soils were identical in composition with the original materials. The drifts from sandy and also from medium loams were poorer in textural grade and chemical composition than the original soils, though in the medium loams the differences were small.

The repeated action of frost is probably responsible for some soil drifting. The action of frost in improving poor soil tilth is actually a detriment in dry farming or on semi-arid soils, which assume a satisfactory tilth naturally.

Soil drifting in Manitoba

Soil drifting as an acute problem, or as a serious source of injury to soils, has been more than normally active in certain sections of Manitoba during the recent drought years. The areas affected are outlined as follows by Ellis (6).

1. The sandy textured soils of the Lake Souris basin.
2. The sandy textured soils of the Assiniboine delta.
3. The sandy textured soils of the wooded area.
4. The prairie soils on drift in south-central Manitoba.
5. The clay loam soils in Western Manitoba.
6. The soils on the heavy-textured deposits of Lake Agassiz basin.

The severity of the drifting varies considerably in these six areas, being of a serious nature in the first and second, but avoidable in the other areas if precautionary measures and careful handling are adopted. The soils affected are mainly those which do not retain their structures under adverse seasonal conditions or tillage.

The damage caused by drifting may be enumerated as (1) erosion, (2) deposition, (3) abrasion and (4) deflation or the separation and removal

of organic materials, colloids and the finer from the coarser soil fractions. This is the most serious source of injury to soils in Manitoba, causing great reduction in water-holding capacity and fertility.

During the summer of 1935, the Department of Soils of the University of Manitoba conducted a soil survey of about 1,774,000 acres in the principal drought and soil drifting areas in Manitoba. A map showing the location and extent of drifted areas in Manitoba has been prepared. Investigations are being conducted into the relation between textural composition of soils and their susceptibility to drifting, as well as into the effect of drifting on soil fertility.

Soil drifting in Saskatchewan

Soil drifting first became a problem of widespread occurrence in Saskatchewan during the period around 1919. The seasons were dry with high winds and the damage to crops and soil through wind erosion was quite extensive at that time. Between the years 1920 to 1930 comparatively little drifting occurred. More recently, however, coincident with drier seasons soil drifting has become so widespread on the arable lands that it must now be viewed as one of the most serious of agricultural problems (7 and 18).

	Approximate area in square miles.	Percentage of total area of zone.
Brown Soil Zone.		
Heavy soils — Silt loam and silty clay soils	2800	9
Heavy soils — clay soils	1700	6
Medium soils — loam and clay loam	4000	13
Light soils	1400	4.5
Approximate total area	9900	
Dark Brown Soil Zone.		
Heavy soils	3500	12.5
Medium soils	1900	7.0
Light soils	2500	9.0
Aproximate total area	7900	9
Black Soil Zone (Park Belt).		
Heavy soils — clay	400	2
Heavy soils — clay and heavy silty loam	100	0.5
Light soils	2000	9
Approximate total area	2500	

Soil drifting occurs with greatest severity in the prairie areas. This includes the brown and dark brown soil zones, but almost any cultivated land of this area is subject to some drifting. In the park land area soil drifting is not so common as on the prairies. The sandy loam soils have drifted severely in many localities, however, and the heavy soils to a smaller degree. The following statement gives the total areas of the most susceptible types of soil and of the percentage of the total area of the zone in which drifting has been general and severe.

Areas of sand are not included. Very little soil as light as sand is cultivated, but if brought under cultivation such land is likely to drift severely in any part of the province. Serious drifting is occurring in some parts of the sand hill areas owing to overgrazing.

A reconnaissance soil survey map of the southern part of Saskatchewan was prepared during 1935 by the Department of Soils of the University of Saskatchewan, under the supervision of Dr. J. Mitchell (18). The area studied has been divided into four major soil zones or belts, corresponding closely to the regions of natural vegetation, which are in their turn related to the broad climatic differences existing in different parts of the area.

The four zones are :

(1) Brown Soil Zone, corresponding to short grass prairie region (S. E. Clarke (9).)
(2) Dark Brown Soil Zone, corresponding to the intermediate prairie zone.
(3) Black Soil Zone, in tall-grass "park" region, more humid climate and heavy grass growth.
(4) Grey Soil Zone, forest vegetation, relatively low in organic matter.

* * * *

In solving the soil drifting problem, one of the first requisites is to determine the soil types and to remove some areas from cultivation as soon as possible ; the widespread application of the best practices so far developed should be stimulated by a proper extension programme ; the attention of investigators should be centred chiefly on developing control methods for the more difficult soils, especially clays (13).

Official action has been taken by the passage through the Dominion Parliament in 1935 of the Prairie Farm Rehabilitation Act, (see Appendix, p. 189) to provide for the rehabilitation of the drought and soil drifting areas in Manitoba, Saskatchewan, and Alberta. Appropriations of $750,000 were provided for the fiscal years 1935-36 and 1936-37, and of $2,000,000 for the fiscal year 1937-38.

The measures adopted under the Act consist principally of encouraging farmers to adopt improved cropping and cultural practices through the agency of the Dominion Experimental Farms, District Experiment Sub-Stations and Agricultural Improvement Associations. Strip farming, cover crops, and the ploughless fallow are being promoted in order to check

soil drifting. In addition, assistance is being given to farmers to secure seed of drought-resistant grasses and trees for shelter belts, and the development of water facilities for livestock and domestic uses. In connexion with this programme, a considerable amount of research work on drought and soil drifting is being conducted both on the Dominion Experimental Farms and by specially planned projects on new District Experiment Sub-Stations and Reclamation Projects.

The detailed development of the Rehabilitation Programme has been largely the work of the Dominion Experimental Farms. Other agencies co-operating include the Provincial Governments and Agricultural Colleges of the three Prairie Provinces, the Geological Survey of Canada, the Water Power and Hydrometric Bureau of the Department of the Interior, the two Railways, the Dominion Seed Branch and the Economics Branch of the Dominion Department of Agriculture.

Previous to the commencement of the P.F.R.A. programme, Illustration Stations located on the various types of soil and in different parts of the Prairie Provinces were operated for the purpose of demonstrating the most efficient farm practice. With the adoption of the programme designed primarily to combat soil drifting and drought, as well as to rehabilitate the devastated areas, additional and larger demonstration and experimental units became necessary. Such Illustration Stations as were adapted to assuming the new and increased responsibility of DistrictExperimental Sub-Stations were so transformed and new Stations established in districts not hitherto served. The function of the District Experiment Sub-Stations embraces all the work formerly undertaken on Illustration Stations but on a larger scale.

Varied trials are being practised on strip farming, cover crop, trash crop, maintaining cloddy surfaces, ploughing *versus* cultivating summer fallow, method of seeding, rotations, width of strips, and autumn seeding of rye. In addition to these cultural methods, studies on the utility and comparison of the various grasses have been commenced and forage crops are being used where conditions indicate that they will be successful. Autumn rye is seeded to secure fodder on some Sub-Stations.

Forage crop and range research

Research on this aspect of the agriculture of the Prairie Provinces is important from three points of view.

(1) Regrassing of drifted and abandoned areas.
(2) Introduction of forage grasses and legumes into a rotation, where possible.
(3) Proper maintenance of range country to avoid overgrazing and maltreatment, and consequent wind erosion.

Forage crop research. In order to have sufficient quantities of seed available for the grass-seeding programme under the P.F.R.A. in the drought and soil-drifting areas in the Prairie Provinces, the co-operation of farmers in the northern part of Saskatchewan was secured. Seed is dis-

tributed to selected growers, who agree to give the Dominion Department of Agriculture first chance to purchase the seed produced from their plantings. This work has been carried out under the joint supervision of the Dominion Forage Crops Laboratory, Saskatoon, and the Dominion Seed Branch in Saskatchewan. Species grown include Fairway crested wheat grass (*Agropyron cristatum*), Grimm alfalfa and non-creeping brome grass (*Bromus inermis.*) Experiments have been made in co-operation with farmers in the Saskatoon district and with the Animal Husbandry Department of the University of Saskatchewan to determine the best method and time of seeding perennial grasses and legumes. The crops used in these experiments consisted of crested wheat grass, brome grass, western ryegrass (*Agropyron*) and sweet clover (*Melilotus* spp.). Grass and clover seed production in Western Canada has reached the point where there is an abundance of sweet clover and brome grass seed, sufficient Western ryegrass and alfalfa, but not enough crested wheat grass.

Forage crops naturally feature in the schemes of crop rotations which are recommended for gradual introduction into farming practice in suitable parts of the Prairie Province. The value of a rotation as a control for soil drifting is discussed later. Here it may be noted that the forage crops which can be cultivated with a degree of success depending on climatic conditions (lack of moisture, short growing season, and wide range from very low to rather high air temperatures in the winter months) may be classified as follows :—

(1) perennial and biennial crops such as slender wheat grass, brome grass, crested wheat grass, alfalfa and sweet clover ;
(2) annual hay and pasture crops, cereals, annual forage grasses and legumes ;
(3) fodder and silage crops, including maize, sunflowers, green oats and other crops suitable for silage ;
(4) root crops.
See (19).

Research on these various crops is in progress at the Dominion Experimental Farms, the Dominion Forage Crops Laboratory, Saskatoon (20), and at the Universities of Manitoba, Saskatchewan and Alberta. Attention is being devoted particularly to the production of superior, drought-resistant, winterhardy varieties of some of the more important grasses and legumes. Sweet clover, alfalfa, crested wheat grass and brome grass are receiving particular attention for the purpose of adaptation to the rigorous conditions of the southern parts of the Prairie Provinces.

As an important factor in the value of grass in control of drifting is the amount of fibrous root material it can produce in a given time, the research carried on by Pavlychenko at Saskatoon on the root system of certain forage grasses in relation to the management of agricultural soils is of particular importance (14). Spaced single plants grown under ordinary field conditions were excavated in blocks of soil of suitable sizes and the root systems freed from the earth in their entirety by the soil-

block-washing method (15). The root systems were studied at seven different stages during the first three years of growth. The number, extent, penetration and spread of both seminal and crown root systems were determined wherever possible. Root material in one and three-year-old sods was thoroughly examined with respect to its nature, condition and amount at various depths and particularly its value in competition with weeds and binding qualities for soil threatened by erosion. The amount and condition of the fibre in the soil where the sods were broken three years previously were also studied.

Range research. In southern Alberta and south-western Saskatchewan there are areas of considerable extent which are unsuited for cultivation. Lack of soil moisture due to scanty precipitation and a high rate of evaporation is the limiting factor on most of the area and it is now generally recognized that the native vegetation constitutes the best crop which can be obtained from them (9 and 10). Most of the range lands are located on the short-grass prairie areas, or what is known as the brown to light brown soil zone, comprising nearly 34 million acres.

There are about 12 million acres of native range pastures in South Alberta and Saskatchewan and an estimated four million acres of abandoned farm lands, most of which will probably revert to their original state ; in addition, there are several million acres of marginal land for grain, the correct utilization of which has not yet been decided upon and whose owners will probably continue to fluctuate between dry land farming and ranching.

The greater part of this range land consists of more or less rolling country, which rises from about 1,800 ft. on its eastern border to over 3,000 ft. at its western limits. In places the prairie is chiefly cut by " coulees ", steep banked, eroded watercourses which are dry during most of the year. Erosion is illustrated best in the " badlands ", rough areas in which constant erosion maintains a soil surface which is either sparsely vegetated or bare. To the west of the prairies lie the Foothills, which in turn give way to the Rocky Mountains. There are large range areas in the Foothills.

Following the year 1915, the range lands experienced a long succession of dry years. Many of the pastures became overgrazed and weedy. Prices of livestock fell to very low levels and stockmen began to realize that there was an urgent need for research work on the range.

During 1927 the Dominion Range Experiment Station, the first of its kind in Canada, had its inception at Manyberries, in south-eastern Alberta. A branch station has since been opened (1935) at Kamloops, in the interior of British Columbia, where overgrazing is still more marked than in the Prairie Provinces.

The research at Manyberries is of direct importance in the study of methods of erosion control on range lands. The principal projects are :

(1) Pasture studies (fundamental plant studies, range management and improvement, grazing capacity and production).

(2) Forage crop production—including the development and testing of varieties of feed crops suited to conditions in the range country as grown (a) under irrigation, as practised by ranchers, and (b) under dry land conditions.

(3) The management of livestock on the range, including the handling, weighing, etc., of livestock, the development of watering places, preservation of fence posts, building of fences, corrals, etc., the testing of different feeds as maintenance rations for the winter months, etc.

The data obtained to date indicate that not less than 35 acres per cow are needed for the grazing season, April 1 to November 15, while an additional 15 acres are needed for the winter season, making a total annual grazing capacity of 50 acres per cow. The grazing capacity of ranges in other parts of the short-grass prairie will vary from this figure in accordance with climatic, soil and biotic factors.

It is of interest to note that, on land rented from the Government, a *minimum* carrying capacity of one head of cattle to 30 acres is stipulated.

Tree planting

The establishment and maintenance of shelter belts on farm homes in the Prairie Provinces are highly recommended and are being encouraged under the P.F.R.A. Increasing numbers of farmers are showing interest in this development and all tree planting activities have been greatly increased. The rehabilitation programme has given these projects added impetus. With the increased demand for trees and shrubs and for the purpose of supplying at a minimum cost, the work of producing seedlings has been extended to all Dominion Experimental Farms and Stations in the drought area. Increased development has also taken place at the Dominion Forest Nursery Stations at Indian Head and Sutherland. A total of 9,000,000 trees and shrubs were to be available for 1936.

A large amount of investigational work has been done on the influence of shelter belts and hedges on soil drifting and soil moisture control. Many observations have been made on the effect of shelter belts in checking wind velocity and on their effect on soil moisture, soil evaporation and crop yields at various distances from the shelter belts.

According to Ross (16 and 17), the list of varieties suitable for shelter belts and for propagating in large numbers at reasonable expense is very limited ; it consists of :—

Caragana (*Caragana arborescens*), a leguminous shrub of Russian origin, exceptionally hardy and drought-resistant, which makes a dense shrubby growth to a height of about 20 feet.

Manitoba maple (*Negundo aceroidis*), a native tree with a somewhat bushy tendency, which will grow to a height of about 40 ft.

Green ash (*Fraxinus lanceolata*), a native, rather slow-growing tree, also very drought-resistant.

American elm (*Ulmus americana*), a hardy native tree.
Native white spruce (*Picea alba*).
Colorado spruce (*Picea pungens*).
Scotch pine (*Pinus sylvestris*).

Soil research

In connexion with the P.F.R.A. programme, a considerable amount of research on certain phases of soil science has been initiated, while certain other soil research projects, already in progress, have been enlarged. This research work is designed to secure accurate data relative to the causes and prevention of soil drifting, the factors affecting soil moisture conservation and the relation of fertility to varying physical, chemical and meteorological conditions in the soil. A new Soils Laboratory was opened in June, 1936, at the Dominion Experimental Farm at Swift Current, Saskatchewan. A considerable body of useful data relating to soil moisture is available from experiments which have been in progress at Swift Current for over twelve years. A specially constructed wind tunnel will be employed in which representative samples of soil may be subjected to the action of wind under carefully controlled conditions. The equipment will be set up in the laboratory where temperature and relative humidity can be controlled (8).

Experimental work is conducted on :

(1) Soil moisture investigations.
(2) Soil fertility investigations.
(3) Soil drifting control investigations.
(4) Studies on the effect of wind on evaporation, soil moisture, soil drifting and crop production.

Economic survey

A comprehensive study of land utilization in Saskatchewan and Alberta is being conducted as part of the P.F.R.A. programme by the Economics Branch of the Dominion Department of Agriculture in co-operation with the Department of Farm Management of the University of Saskatchewan, the Department of Political Economy of the University of Alberta, and the Provincial Department of Agriculture in Alberta. In addition to data obtained from farms still in operation, considerable information has been secured regarding abandoned farms and municipal records are being used to provide data on municipal receipts, expenditures, tax arrears and assessment of farm properties.

Economic analysis is being related to the soil survey. Information regarding the economic returns on farms located on different soil types is essential in a study of the efficiency of methods and practices adopted and the possibility of obtaining a satisfactory living from farms located in such areas. Data are being secured on size of holdings, land tenure, crop yields and livestock production, farm receipts and expenses, cropping practices, livestock carrying capacity, indebtedness, operator's history,

settlement of the area and farm abandonment. This study is the first of its kind to be made in Canada and should be a guide to the future policy of land utilization in these areas.

During 1937 an additional economic survey was conducted by the P.F.R.A. staff in areas of submarginal land. The information secured in this survey has been used in the establishment of community pastures on approximately 800,000 acres of land which has been removed from crop production.

An economic analysis of sheep ranching, one of the principal agricultural industries of southern Alberta, south-western Saskatchewan and southern interior British Columbia, has been published (3). In the principal sheep ranching sections east of the Rocky Mountains, the average rainfall varies from 11 to 16 inches, and very careful management is essential in order to avoid overgrazing and consequent erosion. The necessity for scientific range research in order to determine methods by which the vegetative covering of ranges can be improved cannot be over-estimated.

Agricultural Improvement Associations

The object of these Associations is to encourage the farmers in a community to co-operate in solving their agricultural problems arising from drought and soil drifting by the general adoption of such practices as strip farming, cover crops, suitable rotations and improved cultural methods, best suited to local conditions. Each member agrees to adopt measures calculated to control soil drifting, conserve moisture, destroy weeds, and improve the quality and quantity of the crop produced. Government assistance is offered to the Associations in the form of advisory help, financial assistance, supplies of grass seed and trees.

Water development

An important phase of the P.F.R.A. programme is the development of surface water resources for agricultural use throughout the drought area. The object of this work is to provide supplies of water for domestic, stockwatering, and irrigation purposes by storing run-off water for use during the summer months. Individual farmers receive engineering and financial assistance in the construction of small projects, while larger projects are constructed or rehabilitated for community use.

From the inauguration of the P.F.R.A. programme to the end of June, 1937, a total of 2,042 small projects had been constructed on private farms, including 1,168 dugouts, 718 stockwatering dams, and 156 small irrigation projects. In the same period some 17 large community projects had been undertaken, ranging in magnitude from the storage of a few acre-feet of water to the construction of large irrigation works serving several thousand acres.

A complete programme of water development work will require several years to complete.

Control of soil drifting

No reference will here be made to methods of erosion control in Eastern Canada ; erosion is not yet a serious problem there, and methods to be used, where necessary, will be similar to those used in comparable areas of the United States, described in the section devoted to that country.

Recommendations as to the methods to be used for the control of soil drifting in the Prairie Provinces are given in detail in a Bulletin issued by the Dominion of Canada Department of Agriculture (4).

Strip farming is a method of soil drifting control which does not appreciably alter cropping practices, but it is important to ensure that the best cultural methods are adopted for summer fallow strips, in order to secure as much trash cover as possible, or to maintain the soil in a lumpy condition. Where it is the practice to summer-fallow the land every other year, stripping may be commenced by dividing the field in the year when it is to be fallowed into strips of the desired width, seeding alternate strips to spring grains and leaving the other strips to be fallowed. If the land is fallowed only once in three years, two strips should be seeded to spring grain and the third one fallowed.

Strips are usually laid down in a north and south direction, which is approximately at right angles to the most frequent winds ; strips laid down in this direction protect the soil from winds coming from any direction except due north or due south. Even when a wind blows parallel to the strips, it is not likely to be as injurious as on unstripped fields because the soil on the strips has not been broken down to a drifting condition by other winds.

The width of strip varies with the severity of drifting, but is usually from 10 to 20 rods ; on some light soils strips as narrow as 5 rods are used.

Strip farming has some disadvantages, but if soil drifting is a problem, the inconveniences are far outweighed by the benefits. The soil has a tendency to ridge at the windward edge of the stubble strips. Weeds such as Russian thistle tend to grow along the edges of grain strips. Special methods for handling insect infestations have been developed.

The summer fallow requires special treatment to control drifting, whether it is stripped or not. Two important methods of summer-fallowing land have developed on the prairie, one in which the land is ploughed (ploughed summer fallow) and one in which the land is not ploughed, but is tilled with surface tillage implements only (ploughless summer fallow). The latter is based upon the fact that weed growth is controlled without burying the stubble or other trash in order to leave this material on the surface to form what has been termed a " trash cover " as a protection for the soil against wind erosion. It is necessary that the trash cover should be anchored in the soil sufficiently to prevent the trash from blowing away. When used in conjunction with strip farming, ploughless summer-fallow is an effective method of soil drifting control, in addition to retaining the full benefit of the summer-fallow in controlling weeds and conserving soil moisture.

Ploughed fallows have been found to drift less readily than unprotected ploughless fallows, but they are by no means immune to soil drifting. With a good trash cover, however, the ploughless fallow is less disposed to drifting than a bare ploughed fallow.

A cover crop, consisting of a late summer seeding of spring grain, is a very effective method of control used on summer-fallow in some localities where a fair rainfall is received. The results with a cover crop are not generally satisfactory in the drier sections of the prairie. The chief objection to the use of cover crops is the loss of moisture by transpiration; preliminary results with cereals indicate that the available soil moisture decreases relatively slowly at the beginning of the growth period of the cereal plant, but that a very rapid decrease begins at about the time when the crop has attained a height of about five to six inches. The yields obtained on a cover-cropped summer-fallow are usually about equal to those from crops sown on a bare summer-fallow, although with heavy growth and in dry regions a very serious decrease following such treatment may take place.

Where systematic precautions have not been observed, emergency measures may be necessary. These include :

(1) listing summer-fallow fields in the autumn;
(2) ploughing furrows one rod apart through the field;
(3) ridging by means of the duck-foot cultivator;
(4) application of straw;
(5) disking during winter months.

Since the texture, structure and, to some extent, the composition of soils influence their tendency to drift, methods of treating different soils must be modified to meet the conditions of each soil type. Sandy soils, certain types of heavy clay and soils rich in humus break down into a drifting condition more readily than medium-textured loams and will not maintain a cloddy structure for any considerable length of time. Fallows on these soils must be protected with a covering of stubble, weeds or cover crops. Ploughing is frequently injurious as the surface is soon weathered down to a dust which moves with the wind.

Certain types of farm machinery are of value in connexion with control of drifting, but great care is necessary in their use, as too frequent or too thorough tillage promotes drifting. These types include the field cultivator, one-way disk, rod weeder, disk harrow and spike-tooth harrow. The standard types of seed drills may be adjusted to assist in controlling soil drifting.

Great care is essential in regard to weed control; frequent cultivation of the soil increases the risk of drifting, but weeds must be controlled if soil moisture is to be conserved.

In any area where one or more specific insect pests are likely to cause economic crop losses, the recommendations for the control of soil drifting must be adapted to meet these insect problems. In Western Canada this

applies to wireworms, the wheat stem sawfly (*Cephus cinctus* Nort.), Say's grain bug (*Chlorochroa sayi* Stal.) and grasshoppers (4).

In the drier regions of the prairie, which constitute a very large proportion of the territory, conditions are unfavourable for forage crops; summer-fallow is essential to conserve moisture. A common rotation in these areas is a three-year rotation of summer-fallow, grain, and grain, or the two-year rotation of summer fallow and grain. In very dry areas where land is cheap and grain growing is only auxiliary, it may be advisable to seed part of the cultivated land to crested wheat grass occasionally and leave it in grass until a definite sod is formed before breaking it again for grain farming. On the sandy soils of the plains, which are very susceptible to soil drifting, farmers have been forced to abandon the summer-fallow and to adopt a continuous rotation of a grain crop consisting of wheat and autumn rye seeded directly into the stubble. Other variations may be used for different conditions. Where moisture is sufficient, typical mixed farming rotations may be introduced; these may be of the three-, four- or six-year type, to include grass and intertilled crops.

The problem of reclaiming fields which have already drifted is a serious one. As the top few inches of prairie soils contain most of the organic matter, the application of farmyard manure and the ploughing under of green crops have improved the tilth and productiveness of eroded fields. When fields have drifted badly, other methods have to be employed; in order to study suitable methods the Dominion Experimental Farms have acquired some of these drifting fields for experimentation.

Water erosion in the Prairie Provinces

Although in the more arid parts of the Prairie Provinces wind erosion is very much more important than water erosion, discerning observers can recognize the incipient effects of the latter as well.* Water erosion has been repeatedly noticed on the Peace River tableland. The agricultural portion of the plateau flanking the Upper Peace has an average elevation from 1,800 to 2,500 feet, and is cut by deep river canyons towards which the drainage courses incline irregularly. Even where the fall is slight roadside ditches are transformed rapidly into dangerous gullies, this fact suggesting that soil structure and allied physical and perhaps even chemical factors may play a part. The compact subsoil characteristic of most of these regions does not favour percolation; hence with precipitation even of 17 inches the run-off is sometimes heavy. Irrigationists find that a trickle of water flowing down a slope over dry ground will soon commence to cut a channel, whereas if the soil is first moistened carefully the same flow will be absorbed. The chronically dry condition of the sub-surface soil may be one factor accounting for the erosion of Peace River soils.

In the Peace River and other northerly portions of the Prairie Pro-

*Information on water erosion in the Prairie Provinces and its control has been supplied by W. D. Albright, Superintendent, Experimental Sub-Station for the Grande Prairie District, Beaverlodge, Alberta.

vinces much of the soil tends towards the woodland or podsol type. After the surface layer of leaf mould has been removed these soils seem to lack fibre and lime in their upper horizons. These soils puddle readily when wet and set hard when dry. Running water cuts them quickly, not even the grassed areas being free from its action.

In some parts of the region engineering methods will be necessary but elsewhere trees, meadows and crop remains are of value. By adopting crop rotation on the experimental areas, broad belts of sod or unploughed stubble have been introduced across the direction of the steeper slopes. After the sod land, composed of brome grass with or without alfalfa, is ploughed again no damage occurs for some time. Some of the steeper watersheds require reforestation, while dangerous runways must be laced with tree roots. Where the slope is not extreme and the volume of water not excessive shallow runways have been scraped out and seeded to grass or grass-alfalfa mixtures. Mangum terraces are about to be tried experimentally.

Other precautions adopted include ploughing and autumn cultivation across slopes, and the diversion of spring run-off for the irrigation of dry ridges ; snow water has been employed to increase the production of alfalfa on certain knolls by up to 500 per cent in drought years. It is not so difficult to obtain a good establishment of meadow crops as in the plains to the south.

BRITISH COLUMBIA

Although the first symptoms of the artificial disturbance of the vegetative cover and ground equilibrium by destruction of forests, overgrazing and cultivation are beginning to appear in both humid and semi-arid regions, so far the actual damage has been small (2).

The Fraser River, the largest river in British Columbia, whose basin lies entirely within the Province, is perhaps the best indicator of erosion over a large area and is certainly the greatest carrier of eroded materials. It has a length of 790 miles and drains an area of 91,700 square miles (5).

The small amount of damage from erosion in the drainage basin of the Fraser is largely due to the great extent of virgin territory and the comparatively small area of land that is cultivated. In the vast forest-covered area the second growth is often sufficiently luxuriant to modify the effects of lumbering and fire. The soils, too, are mainly coarse in texture and are, therefore, resistant to erosion. Nevertheless, in humid cut or burned-over forest regions, faster run-off from the watersheds is becoming evident ; this may eventually lead to disastrous flooding in low-lying districts, such as the lower Fraser valley, part of which is diked against the Fraser River.

In the semi-arid interior, erosion is not important except in the irrigated districts where gully and sheet erosion is doing irreparable damage. This is mostly confined to small areas and the amount of destruc-

tion to date has not been sufficient to stir public opinion. In the irrigated fruit-growing valleys of the southern interior the soils are derived mainly from glacial lake deposits and terraces left at former lake levels by tributary streams. Gully erosion is intensified after irrigation systems are installed by the overflowing of excess irrigation water, which finds an outlet on the exposed face of the deposit, causing collapse and the formation of gullies.

The terraces left by tributary streams at former lake levels frequently consist of deposits of open, porous sands and gravels, upon which has been imposed a blanket of sandy loam or other fine soil material from 15 inches to 2 feet or more thick. The furrow system of irrigation generally used has the effect of wearing down the soil blanket until the underlying gravel is exposed, thus causing destruction of the land by a gradual process. Such land has been in use for about 30 years and "shallow phases" of this profile are already in evidence.

The two examples of erosion noted, in irrigated land, are mainly confined to small areas amounting to a few acres here and there, but the land so destroyed is the most valuable in the Province and cannot be replaced. The amount of such land available for future development is very limited.

APPENDIX

Prairie Farm Rehabilitation Act

During the 1935 session of the Dominion Parliament, this Act was passed to provide for the rehabilitation of the drought and soil-drifting areas in the Provinces of Manitoba, Saskatchewan, and Alberta.

Amendments to the Act were passed on March 31, 1937.

Under the terms of the amended Act, the Governor-in-Council may establish one or more Advisory Committees to be known as Prairie Farm Rehabilitation Committees. During 1937 three Advisory Committees were established as follows :—

(1) The Prairie Farm Rehabilitation Committee.
(2) The Water Development Committee.
(3) The Land Utilization Committee.

"The Advisory Committees shall consider and advise the Minister (of Agriculture) as to the best methods to be adopted to secure the rehabilitation of the drought and soil-drifting areas in the Provinces of Manitoba, Saskatchewan, and Alberta, and to develop and promote within these areas systems of farm practice, tree culture, water supply, land utilization and land settlement that will afford greater economic security and to make such representations thereon to the Minister as the Advisory Committees may deem expedient."

Provision is made in the Act for the appointment by the Minister of technical and other workers subject to regulations by the Governor-in-Council.

"For the purposes of this Act, the Governor-in-Council may from time to time authorise the expenditure in each of the fiscal years 1937-38 to 1939-40 inclusive, of sums not exceeding the amount appropriated by Parliament in each year for such purposes."

References (Canada)

1. Aberystwyth, Imperial Bureau of Pastures and Forage Crops. Correspondence regarding soil erosion in Eastern Canada, from E. S. Hopkins. June 5th, 1937.
2. ——— [Memorandum on] Soil erosion in British Columbia. By C. C. Kelley. 1937. pp. 3. [Typescript.] 5 references.
3. Canada, Department of Agriculture. Publ. 551. Fmrs.' Bull. No. 25. An economic analysis of the sheep ranching industry in Western Canada. By L. E. Kindt. 1936.
4. ——— Publ. 568. Fmrs.' Bull. 32. Soil drifting control in the Prairie Provinces. By E. S. Hopkins, A. E. Palmer and W. S. Chepil. Ottawa, 1937. pp. 51. [New Edition of Bull. 179.]
5. Canada, Geological Survey. Guide Book No. 8. 1913. pp. 256, 271. [By C. Camsell.]
6. Canada, Regional Committee on Soil Drifting. Appointed under the National Advisory Committee on Agricultural Services and the Prairie Farm Rehabilitation Act. Report of Conference held at Lethbridge, Alta. June 28 and 29, 1935. pp. 54. [Mimeographed.] [Soil drifting in Manitoba, by J. H. Ellis, pp. 9-13.]
7. ——— [The extent and areas subject to soil drifting in Saskatchewan, by J. Mitchell. pp. 14-7.]
8. ——— [Research studies on soil drifting under laboratory conditions, by S. Barnes, pp. 33-5.]
9. Clarke, S. E. Pasture investigations on the short-grass plains of Saskatchewan and Alberta. *Sci. Agric.* **10.** 732-49. 1930.
10. ——— and Tisdale, E. W. Range pasture studies in Southern Alberta and Saskatchewan. *Herb. Rev.* **4.** 51-64. 1936.
11. Hutton, J. G. Soil erosion and soil ruin in South Dakota. *Bull. Amer. Soil Survey Assoc.* **16.** 123. 1935.
12. Moss, H. C. Some field and laboratory studies of soil drifting in Saskatchewan. *Sci. Agric.* **15.** 665-79. 1935.
13. Palmer, A. E. The soil drifting problem in the Prairie Provinces. *Sci. Agric.* **16.** 264-5. 1936.
14. Pavlychenko, T. K. Root systems of certain forage crops in relation to the management of agricultural soils. *Bull. Ecol. Soc. Amer.* **17.** 28-9. 1936.
15. ——— The soil-block washing method in quantitative root study. *Canad. J. Res.* **15.** Sect. C. 33-57. 1937.
16. Ross, N. M. Tree-planting in the semi-arid area of Canada. *Emp. J. Exp. Agric.* **4.** 47-50. 1936.
17. ——— The role of trees in modifying the agriculture of the dry areas of the prairie provinces. *Sci. Agric.* **16.** 266-9. 1936.
18. Saskatchewan, University College of Agriculture. Soil survey report No. 10. Reconnaissance soil survey of Saskatchewan from the International boundary on the south to the top of Township 45 on the north. Saskatoon, 1936. pp. 120. maps.
19. Saskatchewan, University of, Department of Agriculture Extension. Guide to Saskatchewan agriculture. Saskatoon, 1936. pp. 90.
20. Stevenson, T. M. The improvement of sweet clover (*Melilotus*) in Western Canada. *Herb. Rev.* **3.** 123-7. 1935.

West Indies

JAMAICA

Jamaica is extremely hilly. Its highest point on the Blue Mountains has an elevation of 7,360 feet and every altitude and degree of slope is found between this and the plains, which comprise less than 15 per cent of the total area of the island and are composed chiefly of alluvium, marl and swamps.

A considerable variety of climates is found, temperatures varying from 80 to 86° at the sea coast to 45 to 50° on the tops of the highest mountains. The wettest part of the island, where considerably more than 100 inches of rain fall each year, is on the tops and northern slopes of the Blue Mountains, whereas the driest part, in the centre of the south coast and a strip on the north coast, has a rainfall of less than 40 inches per annum; the annual average for the whole island is about 67 inches.

The Government of Jamaica have recognized the need of strengthening its forest policy for some years. The Afforestation Law 33 of 1927 had proved unworkable in practice and it was recognized to be necessary to embark upon a new investigation in the hope that it might be found possible to establish a division of forestry charged with the duties of forest protection, maintenance and extension. Public opinion was in accord with this view and the Jamaica Imperial Association at its annual general meeting on April 25, 1934, resolved to impress upon Government the importance of a better system of afforestation in Jamaica, and to request that steps should be taken to secure assistance from the Colonial Development Fund for a study of forest conditions in Jamaica, and the lines along which they might be improved.

In response to an application from the Government of Jamaica a grant was made to cover the expenses of an investigation, and Mr. A. Wimbush (Chief Conservator of Forests, Madras Presidency), was chosen to undertake the work. It was found possible to combine a similar investigation in the Windward and Leeward Islands with an examination of the position in Jamaica (7).

In the 400 years under consideration, during which time coffee, sugar, bananas and citrus fruits have been the chief crops cultivated, in amounts which have increased or decreased from time to time, there has naturally been a very great increase in the population of Jamaica, with the result that the demand for land increased also. During the course of years many of the larger estates have been split up by sale of small lots to labourers on the estate or their descendants. Again the demand for land for growing foodstuffs has been met to a great extent by a system of renting small areas to tenants. These tenants have, for years past, practised shifting

cultivation ; with the result that large areas have been denuded of their original forest growth. It very frequently happens that a man who is paying rent for, say, one acre burns and destroys forest on a very much larger area.

Accessible areas of forests have been heavily over-exploited, every saleable tree being cut long before it is mature ; a limited area, especially in the interior of the Cockpit Country, still contains valuable tropical forest with large trees of useful species. Only one Reserved Forest or, strictly speaking, series of Forest Reserves has been notified so far. This is in the Blue Mountains, where sixty-seven blocks of land, mostly old properties forfeited for failure to pay taxes, have been declared Forest Reserves. The boundaries exist only on paper and, owing to the existence of private estates, are irregular in the extreme. According to Wimbush, the only thing which causes surprise to one who leaves the path and trees and tries to scramble up the precipitous slopes, over the very loose shaly soil, is that the damage has not been greater. There are thousands of tons of the loosest possible soil waiting for the next abnormal downpour of rain to wash it down into the Yallahs Valley and its tributaries.

As regards private lands, Wimbush reports that the present state of affairs varies greatly in different localities. In the majority of parishes, practically all land fit for producing valuable plantation products has been cleared for cultivation, as is very natural and correct. A great deal of land, however, which is much too steep for any form of permanent cultivation has been disposed of to petty settlers, either permanently or on lease, and it is these men, practising shifting cultivation for the production of foodstuffs, who do most of the damage at present, although in the past it was the clearance of forest for coffee growing on the shale soils of the Blue Mountains that caused the most serious and lasting damage by way of erosion and rapid run-off of rain water.

The Wimbush Report on the forestry problems of Jamaica concludes with recommendations for the future handling of the problem. It is admitted that it has taken Jamaica several hundred years to reach its present state as regards deforestation, and what is attempted in this Report is to take a broad outlook for many years ahead. Small scale operations should be started at once, preferably on an accessible demonstration area such as the catchment area of the Kingston water supply.

Developments in Jamaica in connexion with the conservation programme include :

(a) The formation of a Forestry Branch and expanded reforestation programme.
(b) Efforts to encourage private tree planting.
(c) Acquisition programme of Government.

Soils of Jamaica

The soils subject to erosion in Jamaica may be broadly classified as (1) soils of shale and conglomerate origin ; (2) soils of limestone origin (terra rossa) (3).

The soil of the Blue Mountain area belongs mainly to the first type. Fortunately, the rocks forming the soil are relatively soft and easily disintegrated, and it is because of this factor that the effects of erosion are not so great as would be expected, considering the treatment that the soils have received. There are also certain weeds and shrubs which under the high rainfall cover fairly rapidly once the cultivated area is abandoned. The growth so formed, however, restricts rather than promotes the establishment of trees. Such areas, after a few years, may again be brought into cultivation and further deterioration of the soil, which will have only partially recovered, occurs.

The soil derived from the limestone is typical terra rossa, loose and friable and easily detached from the hard underlying rocks. The soil covering is maintained on hillsides only by the presence of trees and by the natural irregularity of such areas. There is a tendency for soil to accumulate in small pockets. Once the vegetable covering is removed, the greater part of the soil is easily washed from the rock. The soil formation is relatively slow and there is little opportunity for cover to re-establish itself. Once such areas have been exposed and eroded there is little chance of their becoming productive again for very many years.

PUERTO RICO

The greater part of the American Island of Puerto Rico is hilly or mountainous and subject to torrential rainfall. The muddy streams indicate a part of the erosion which is going on and which has been accentuated by years of hillside cultivation. Deforestation has been more complete and consequent damage much more severe in Puerto Rico than in Jamaica. A large proportion of the soils of Puerto Rico are very heavy clays which appear to be comparatively resistant to erosion. Yet the heavy tropical rainfalls, coupled with the nature of the topography, have made erosion a very important factor in the agriculture of the Island. The heavy nature of the soils has resulted in much sheet erosion, as well as gullying. Many of the hillsides have completely lost their surface where improperly managed, and crops are now being grown on the comparatively unproductive surface soils produced from former subsoils. Where general field crops such as maize and tobacco are grown on the steep hillsides, damage from soil erosion is very great during heavy rainfall (5).

The ridges of the hills consist only of hard subsoils upon which vegetation of any kind has difficulty in maintaining itself. Even the areas devoted to coffee culture, in which the soils are seldom disturbed by cultivation, experience severe erosion losses. Studies of control measures are now in progress and permanent reconstruction is dependent not only upon checking erosion, but also upon a plan of restoration of plant nutrients to soils already badly depleted by erosion.

On the land of the Puerto Rico Agricultural Experiment Station, Mayaguez, terracing has been continued with the construction on steep

inclines of flat terraces, with drops of three to six feet between terrace levels. Two years after setting with *Cordyline guineensis* some terrace banks had been fairly well protected against washing; Guatemala grass (*Tripsacum* spp.) covered the ground much more rapidly, but for a permanent stand is considered less desirable for binding the soil on the banks of narrow terraces on account of the shading effect of its rank growth.

According to the Report of the Soil Conservation Service (6), a reconnaissance erosion survey has been made. No apparent erosion was found on about 12 per cent of the island, and slight erosion on 19 per cent of the area, mostly on cultivated parts of the coastal plains and alluvial valleys or on gently rolling pasture lands (2). Moderate erosion was found on 29 per cent, and severe erosion on about 39 per cent of the area. Most of the severe erosion occurs in the rough mountainous interior. Sheet erosion was the most common type, with gullies occurring on a little less than 22 per cent of the total area.

WINDWARD ISLANDS

The Windward Islands include Grenada, St. Vincent and St. Lucia, and a chain of smaller islands called the Grenadines, lying between Grenada and St. Vincent. The Government forests are essentially tropical evergreen protection forests, situated for the most part on the most inaccessible parts of the very hilly country.

When Marshall (4) reported on the forests of Grenada in 1932, the position was described as highly unsatisfactory and it was recommended that in the interests of agriculture, additional areas, mainly of mountain land, should be reserved and kept permanently forested. The Report also drew attention to the lack of provision that had been made for keeping the sources of a number of rivers under forest; to the promiscuous manner in which shifting cultivation was being carried on, except on some estates where the ridges were kept forested; and to the fact that practically no attention had been paid to the retention of forests as windbelts.

According to Wimbush (8), although the view from St. George might lead to a contrary opinion, Grenada, as a whole, is a well-wooded island at the present day. Large areas are covered with plantations of cocoa and nutmeg which appear to afford admirable ground cover, and, generally speaking, private landowners have usually been able to keep the ridges and hilltops under woodland. Practically no complaints have been heard in Grenada of a serious decrease in recent years in the flow of water in the rivers and very little sign of really serious denudation or erosion has been noticed. Framers of a forestry policy, however, must look ahead for at least a hundred years, and in the interests of the island it is essential that any further clearance on the hills should be stopped. Some private owners would prefer to enforce this policy themselves, but Wimbush suggests that any form of dual control should be avoided.

All Crown Lands in St. Vincent situated above 1,000 feet have been reserved in order that they may be protected from any act that would be

prejudicial to the conservation of the forests growing on them. Wimbush states that no line has been cleared to demarcate this level and numerous instances of cultivation within the Crown Lands at elevations above 1,000 feet were noticed.

From the point of view of forestry, a critical stage has now been reached in St. Vincent. The prosperity of the island is dependent largely upon an adequate perennial supply of pure water; this is particularly necessary for the arrowroot industry, which supplies most of the requirements of the whole world as far as this commodity is concerned. The flow of clean water is no longer what it used to be, and pumping has had to be adopted in some cases. The banana industry is now being developed in St. Vincent and a knowledge of what has happened in Jamaica makes it very easy to foresee an increasing pressure upon the forest land in St. Vincent for banana growing.

In St. Lucia the forestry problem is complicated owing to the peculiar circumstances relating to the ownership of the land, dating from the time when the island was taken from the French and an undertaking was given that the owners of landed property at the time of conquest would not be interfered with.

Fifty years ago the area of Crown Lands was estimated to be about 500,000 acres; an estimate of the area still remaining undisposed of is between 12,000 and 13,000 acres, amounting to about nine per cent of the total area of the island.

The forest on this comparatively small remaining area of Crown Land is constantly being further encroached upon by practisers of shifting cultivation, and also by timber fellers. In St. Lucia, shifting cultivation has already ruined vast areas of the island and the process is continuing at an alarming rate with the result that the productivity of the island is being diminished rapidly. This is serious from an agricultural point of view, and yet according to Wimbush, there is a sanctioned scheme on foot which must involve the clearing of more and more of the Protection Forest around the headwaters of the chief rivers of the island, in an area of the best remaining banana soils which is remote from the old banana areas known to be infected by Panama disease.

Wimbush considers that an executive order instructing the Commissioner and the Rangers to stop further clearing of any kind is highly desirable, until a decision on his report has been taken. When once evergreen protection forest in St. Lucia has been destroyed, it cannot be restored and the "squatting" which has already assumed really serious proportions is being stimulated by extension of banana growing.

The firewood and charcoal industry on St. Lucia is also active, but the soil cannot continue to yield fuel indefinitely if it is cleared and exposed every five years or thereabouts, as is the present practice. It is suggested that private owners should subdivide their fuel forests into about 25 annual felling areas or coupes, and insist that felling should be confined to one area per annum.

LEEWARD ISLANDS

Wimbush also visited Montserrat, St. Kitts, Nevis, Antigua and Dominica in the Leeward Islands (8). While making his tour of the Lesser Antilles, he found it impossible to formulate his ideas about the Windward Islands and the Leeward Islands quite separately. Notes are again submitted for each individual island of the Leeward Islands, but the main proposal relating to the appointment of one trained Forest Officer, attached to the Trinidad Conservator, for the whole of the Lesser Antilles, is common to both the Windward and the Leeward Islands.

The primary essentials for a scheme of forest protection already exist in Montserrat, but certain improvements are necessary. The forests of this island have suffered very great damage from hurricanes and almost all the trees of any size were uprooted or destroyed in 1928. In addition, the recent earthquakes have caused a great many landslips and the mountains are badly scarred.

In St. Kitts, as far as the mountains of the interior are concerned, the forests are protected most strictly by the private owners of the land for the good of the island as a whole, and generally speaking there is a strong public feeling in favour of the forest restrictions and willingness upon the part of the estate owners and managers to co-operate with the Forestry Board in their work of preventing encroachment upon the forest land by petty cultivators or exploiters of firewood and charcoal. This is done, however, at the expense of the forests of Nevis, from which most of the charcoal used in St. Kitts is brought. Wimbush considers that it would be possible to harvest the forest resources in both islands without reducing the protective character of the forests.

Antigua, with its comparatively low rainfall (44 inches) and its shallow soil, carries a less spectacular type of forest than the other islands. Sheet erosion over a period of years has been responsible for the very shallow soils overlying the limestone in some parts of the island. The annual burning of hills and waste lands is a hindrance to reforestation. Attempts are now being made to check cultivation of steep hillsides.

For both Windward and Leeward Islands, Wimbush recommends the primary essentials for a scheme of forest protection, namely :—

(1) Areas selected for protection.

(2) An Ordinance or Law giving power to enforce protection.

(3) Some staff under an officer subject to the control of a Forestry Board for enforcing the regulations.

TRINIDAD

In Trinidad the fact that the principal crop is a perennial (cocoa) has been responsible for minimizing to some extent the degree of erosion as compared with the losses that would have occurred had the land been planted with annual crops. Further, the Colony is provided with ample

Forest Reserves which have, as far as these areas are concerned, prevented destruction of forest cover. In 1933 it was estimated that the percentage of forest area to total land area amounted to 46 per cent (1).

Soil erosion in this Colony is, however, in some places a source of serious loss of soil fertility. In the last few years, in the westerly portion of the Northern Range, there has been an increase in the felling of forest on privately owned lands in the foothills for the planting of annual crops. With the removal of forest cover which at first was more or less confined to the lower slopes, but which now has been extended to the summits of some of the hills, damage has already been caused by the drying-out and erosion of the soils, by shortage of waters in the springs and streams during periods of fair weather and by extensive floods during periods of heavy rainfall. The very severe floods which have occurred in the Maracas Valley and in the Caroni plain must be largely attributed to the rapid and unchecked flow of waters down the denuded hillsides of the Northern Range. Any further undue interference with the forest cover of these hills will cause more extensive damage to the agricultural undertakings in the lowlands. Agriculture on the upland regions has already been affected. Much of the soil where patches of forests have been burnt for making gardens, which are abandoned after a year or two, is practically useless. Where forest windbreaks have been removed, some of the cacao plantations have also suffered ; the uniform humidity which cacao requires has been upset and arid periods occur. Considerable damage has been done to roads and property by landslides on the steeper slopes.

The process of deforestation has undoubtedly been accelerated by the depression in the cacao industry, since planters have resorted to the policy of encouraging peasant gardens with the object of keeping their skilled labour on the spot ; this results inevitably in shifting cultivation owing to the rapid deterioration of the thin soil on the steep hillsides. At the same time, the very grave dangers of deforestation cannot be overlooked and steps have already been taken by the Trinidad Departments of Agriculture and Forestry to deal with the situation. It has been urged that no further land should be alienated on the slopes of the Northern Range without the joint sanction of the Director of Agriculture and of the Conservator of Forests. Propaganda has been inaugurated with a view to inducing the larger estate owners to prohibit shifting cultivation on their estates, and consideration is being given by the Lands Advisory Committee to asking Government to vote a sum of money annually for the acquisition of land from small proprietors in zones of particular danger.

References (West Indies)

1. Aberystwyth, Imperial Bureau of Pastures and Forage Crops. Correspondence re soil erosion in Trinidad from the Director of Agriculture. Port of Spain, 28 January, 1937. p. 1.

2. ———————————————— Correspondence re soil erosion in the West Indies, from Staff of Soil Conservation Service. Washington, 7 December, 1937. pp. 3.
3. ———————————————— Correspondence re soil erosion in Jamaica, from the Director of Agriculture, with notes prepared by the Forest Officer and Agricultural Chemist. Kingston, 20 December, 1937. pp. 4.
4. Marshall, R. C. Report on Forestry in Grenada. Grenada, 1932. pp. 17. maps.
5. Puerto Rico Agricultural Experiment Station. Annual Reports.
6. United States, Department of Agriculture, Soil Conservation Service. Report of the Chief of the Soil Conservation Service, 1936. Washington, 1936. pp. 52.
7. Wimbush, A. Report on the forestry problems of Jamaica. Jamaica, 1936. pp. 10.
8. ———— Report on the forestry problems of the Windward and Leeward Islands. Trinidad, 1936. pp. 21.

Australia

Australia, in many respects topographically and climatically similar to the semi-arid regions of the United States, has encountered also similar erosion problems. Mr. E. S. Clayton (4) has stated that " worse examples of wind erosion are already to be seen in Australia on both grazing and cultivated lands than in the United States or Canada. . . . . The position in regard to water eros on is also very serious. It has not progressed so far as in the United States, but the land has only been under cultivation for about one-third of the period." Wind erosion, on account of its widespread occurrence in the semi-arid interior, has attracted somewhat more attention than water erosion which has been observed principally in the mountainous districts of the Murray River catchment area.

In a memorandum prepared in 1935 by the Standing Committee on Agriculture of the Council for Scientific and Industrial Research, Professor A. E. V. Richardson states: " I take it that the problem . . . . . is really the deterioration of pastoral lands in arid and semi-arid country of Australia—Central Australia, western and south-west Queensland, western New South Wales, the north of South Australia, and the drier pasture areas of Western Australia. Over this huge stretch of country the combination of over-stocking, dry seasons, but particularly the depredations of rabbits, have resulted in the gradual deterioration of hundreds of thousands of square miles of lightly stocked pastoral country. The rabbit is probably the most important factor in bringing about this deterioration. In a run of good seasons, grass and herbage, as well as the perennial elements in the pastures (the saltbushes, bluebushes) grow amazingly, and this superabundance of food leads to rapid and enormous increases in the rabbit population. In due course the inevitable dry seasons supervene and the rabbits exact heavy toll of the perennial elements (the saltbushes and bluebushes) which form the natural vegetative cover of the arid and semi-arid pastoral areas. Even the mulgas are heavily ringbarked by the rabbit, and when a drought occurs there is widespread and wholesale destruction of the herbage and trees. With a succession of bad seasons the drift commences and huge areas of pastoral country are devastated.

"The drift in the Mallee areas is another and separate problem. Here the settler has deliberately removed the whole vegetative cover to grow wheat, fallowed up the land to provide a seed bed, and strong winds acting on a light sandy soil have led to drift on a perfectly amazing scale in some districts. This is common to South Australia, Western Australia, Victoria and New South Wales. In these cases the drier the areas and the lighter the soil, the worse is the damage."

During the last 25 years, soil drift in the Mallee* has been greatly

*Mallee soils are saline and/or alkaline, formed under a low winter rainfall and within the influence of the southern ocean (9).

accelerated by the high wheat prices ruling during and after the war, coupled with unusually moist seasons from 1915 to 1926 when farmers seized the opportunity to increase their capital resources at the expense of the soil, by overcropping with cereals (7). Then followed a period of low prices and dry years when the disastrous consequences of soil exhaustion were fully displayed. The most practicable method of control is to preserve adequate windbreaks; strip farming is not readily adaptable to Victorian conditions, but sowing and grazing oats and other means for introducing organic matter into the soil have been found effective (5).

The C.S.I.R. memorandum quoted above gives the following* summary of a report issued in 1933 of a Sand Drift Committee appointed by the Victorian government.

Sand drift is due in a great measure to indiscriminate clearing of the natural growth in course of settlement and to the thoughtless cultivation of sandy areas on which the natural cover should be allowed to remain as a protection against sand drift. Practically all the trouble to public works and fences comes from drift which is carried comparatively short distances. This is not in accord with the prevailing idea that drift carries for miles.

The menace will increase, particularly in the newer settled Mallee, as it becomes more cleared and cultivated. The prevention or minimizing of sand drift is imperative and would best be dealt with by legislation.

In South Australia and in Western Australia, where the sand drift problem is acute, Sand Drift Acts have been in operation for 9 years and 43 years** respectively, in order to protect roads, railways and private property. Legislation of such far-reaching character is hardly deemed to be necessary in Victoria.

Evidence taken in South Australia indicated that the Sand Drift Act in that State had worked successfully. Action had been taken with excellent results in controlling fallowing and burning off, in the sowing of summer crops on sandy ridges on farm lands and on roads where the crops were allowed to seed down each year. The drift in the areas inspected in South Australia was not so bad as in the areas inspected in Victoria.

The Committee recommended that suitable legislation should be introduced to check the misuse of the Mallee, but at the time of writing (1937) none has been introduced, and there appears to be some opposition among wheat growers against government action until the position has been further clarified by research (5).

Griffiths (7) gives as the main causes of wind erosion in South Australia (1) removal of the natural cover, (2) the use of fire for destroying either virgin growth or crop residues, (3) overcropping and bare fallowing, and (4) overstocking, to which rabbits largely contribute as well as starting blow-outs by their burrows. One or more of these conditions prevail on most wind-eroding areas throughout the world, but the rabbit menace is peculiarly Australian. Rabbits, in association with drought, are usually cited

*Not quoted in full.
**i.e.*, from 1933.

as the prime causes of soil drift, but Ratcliffe (10, 11) considers that their importance has been over-emphasized, at least in connexion with the semi-arid South Australian pastures. Soil drift is most extensive in the bush country where it is estimated that as a direct result of overgrazing the bush cover has been reduced to 10-25 per cent of its original density. As a result of twelve drought years overstocking on established farms has become almost unavoidable. Rabbit infestations occur only in good seasons, and persist only so long as annual green herbage is obtainable. Ratcliffe states that rabbits do not seriously attack the saltbushes and bluebushes that form the perennial cover of the sandy-loam soils, but they undoubtedly act as an accessory factor in producing drift by forcing the sheep back onto the bush reserve before this would otherwise have been necessary. In other words, rabbits cause symptoms of overstocking to appear at exceptionally low stocking levels. The bush country is entirely unsuited to stocking at a constant level, and in the past the mistake has commonly been made of estimating the level on the basis of a good or even moderate season. On the other hand, the vast sandhill areas of mulga (*Acacia*) scrub appear to be irretrievably doomed to drift unless the rabbit can be exterminated, as it effectively prevents regeneration of the scrub. The scrubland carries an ephemeral herbage vegetation and " the only safe way of utilizing sandhill country is to stock it heavily while the flush of ephemeral feed is on (and the heavier it is stocked the less feed there will be for the rabbits), and to remove all stock completely before the plants have been eaten down to the roots and the surface cut about too much."

According to Ratcliffe, the chances of any appreciable recovery in the eroded pastoral areas must depend on a readjustment of stocking policy. Light stocking is essential if the hardier native pasture plants such as spear-grass (*Stipa nitida*) and the "bindy-is" (*Bassia* spp.) are to establish themselves on the formerly bush-covered areas. If low-growing native plants could be established on the denuded land, much of the drifting sand could be effectively held, but the big moving sandhills present a more difficult problem. The native plants that might have served to bind the sandhills are those most susceptible to rabbit attack, and in any case their establishment under the prevailing conditions would be very slow indeed. The only hope for these areas is to discover an exotic plant, preferably with a rhizomic habit of growth, distasteful to rabbits, and capable of flourishing under an irregular rainfall of 6-9 inches a year. The chances of discovering such a plant seem remote, and if discovered, the economic problem will remain of how to disseminate it over vast areas with no regular growing season and an exceptionally low unimproved capital value. The South Australian Government (12) has recently introduced a scheme for reducing pastoral rents with special consideration for lessees who agree to reduce their stock, fence off affected areas, and set aside permanent reserves for seeding native plants and trees. What more fundamental measures for saving the arid pastoral regions could be undertaken with reasonable hope of success is still an unsolved problem.

Soil drift on New South Wales pastures has not been so serious as in South Australia, although the productivity of large areas has been greatly reduced by rabbits and overstocking. The rate of damage, moreover, appears to be decreasing, and settlers are making spontaneous efforts to control the causes. A government committee, consisting of the Catchment Areas Board and a Soil Erosion Committee, was formed in 1933 and has carried on active educational work with very good effect. The Western Lands Office recommends denser settlement without overstocking, as this tends to reduce rabbit infestations, and suggests other methods of rabbit destruction and reforestation while recognizing that the cost of these measures would be out of all proportion to the immediate economic benefits derived from them. In Western Australia (13) the granitic soils are much less susceptible to drift than the sedimentary soils in the east, and in Queensland the climate has to a great extent prevented overstocking, while rabbits only become a serious menace in exceptionally good seasons.

According to Professor J. A. Prescott*, water erosion is probably limited to regions having an average rainfall of more than 0.4 inch per wet day. This would confine it to certain mountainous districts and to a coastal strip and the northern part of New South Wales, besides the largely undeveloped northern half of the continent (9). The Murray River catchment area, where water erosion has chiefly been observed, occupies one-seventh of the total mainland area and, together with the narrow coastal strip between it and the sea, contains three-quarters of the population (14). The rich lands of the Upper Murray were among the earliest to be occupied, the land above 2,500 feet and extending to the Alpine grasslands is mainly held under licence by graziers who burn out the rank grass in summer to encourage sweet undergrowth in the following spring. These fires often extend into and destroy the higher situated forests which have also been extensively denuded for settlement. Both sheet and gully erosion are very extensive. " The suggested methods of dealing with the question are, firstly to carry out a detailed survey and land classification to determine the most economic use to which each portion of the catchment should be put, and delineation of the sectors which are required to be maintained permanently as forests. Secondly, the vulnerable sections of the catchment area should be dedicated as forest reserve, reforestation of denuded areas should be carried out and, if necessary, the resumption of private lands by the Crown should take place for this purpose. Thirdly, adequate provision for protection of forest areas from fire. Fourthly, revision of the methods under which highland areas are leased for grazing. And finally provision to be made for subsidiary control measures, such as river plantings and establishment of minor structures on upper reaches of streams to prevent further erosion pending improvement to highland sectors."

*Private communication.

A preliminary survey of the mountain districts has been made by Byles (1), but the work was curtailed for financial reasons. This region, the only part of the mainland having a distinctly cold climate facies, is important as the main source of water for the irrigation settlements in the surrounding plains. The higher land is used for grazing, and the administrative problem is to reconcile pastoral occupation with the protection of the catchment from deforestation and erosion (6). Byles found that, contrary to the usual idea, the mountain pastures were generally understocked, necessitating fires to destroy the surplus grass. Understocking was particularly apparent in the "snow-gum" country, where the snow grass (*Poa caespitosa*) is the principal species. This is grazed very lightly, and unless the land is heavily stocked there is, at the end of the season, a large carry-over of herbage which can only be got rid of by burning. The worst area, however, is the burnt-over Alpine-ash country where four factors—a very fire-sensitive species, steep slopes, heavy rainfall and a loose granitic sandy soil—have combined to produce widespread sheet erosion and deep and growing gullies. Byles's recommendations followed the same general lines as those quoted from Galbraith above, emphasizing the need for instituting grazing control.

Sheet and gulley erosion are severe on the wheat lands in New South Wales where numerous gullies 7-8 feet deep and 9-10 feet wide have developed during the last decade (2). The position is growing visibly worse each year. Much of the land would now be recognized as too steep for cultivation, and would be safer as pasture, especially if contour drained. Orchards have suffered heavily, being often situated in undulating country. Clean cultivation is regarded as essential to conserve soil moisture, and Clayton (3) suggests green manuring and contour banking as suitable erosion-control measures. In the coastal dairy districts very rapid erosion follows cultivation of maize and fodder crops.

Water erosion is also occurring in the cotton belt in Queensland, but has not been much studied. The position, however, is being watched carefully.

Mr. C. G. Stephens (8) has drawn attention to the widespread occurrence of sheet erosion in Tasmania, particularly on the basaltic soils in the north. "On this rolling country with its red, brown, or chocolate soils which are readily self-mulching, loss of surface soil appears to be taking place intermittently. When left in a loosely cultivated state, and during heavy rain showers large quantities of soil are frequently removed from the sloping ground. Often as much as one inch of surface soil may be removed in a rain storm. Instances have been observed where over a period of years the whole of the surface soil has been removed, either being washed into streams or lodged lower down the slope. Owing to the slight change in colour between the surface soil and subsoil in these areas, and to the fact that the type of soil removal is generally sheet erosion, this loss of surface soil is not readily detected by the untrained eye." The southern apple-growing districts are also affected locally by severe water erosion, while

wind erosion has commenced on King Island (under Tasmanian administration) and threatens to spread.

References (Australia)

1. Byles, B. U. A reconnaissance of the mountainous part of the River Murray catchment in New South Wales. *Commonwealth Forestry Bur. Bull.* 13. pp. 34. 1932.
2. Clayton, E. S. The control of soil erosion on wheat lands. *Agric. Gaz. N.S.W.* **42.** 825-32. 1931.
3. ———— Control of erosion on orchard lands. *Agric. Gaz. N.S.W.* **46.** 3-7. 1935.
4. ———— Soil erosion. Investigations overseas. *Agric. Gaz. N.S.W.* **48.** 181-5, 194, 243-7, 254, 312-6. 1937.
5. *The Countryman*, Melbourne. March 25, 1937.
6. Craft, F. A. The snow country of New South Wales. *Australian Geographer* **2.** No. 3, 28-32. 1934.
7. Griffiths, R. L. Wind erosion of soils in the agricultural areas. *J. Dept. Agric. S. Aust.* **40.** 25-40. 1936.
8. *Hobart Mercury*. April 17, 1937.
9. Prescott, J. A. The soils of Australia in relation to vegetation and climate. *Australia C.S.I.R. Bull.* 52. pp. 82. 1931.
10. Ratcliffe, F. N. Soil drift in the arid pastoral areas of South Australia. *Australia C.S.I.R.* Pamph. 64. pp. 84. 1936.
11. ———— Further observations on soil erosion and sand drift, with special reference to South-Western Queensland. *Australia C.S.I.R.* Pamph. 70. pp. 28. 1937.
12. South Australia. Department of Lands. *Annual Report.* p. 7. 1935-1936.
13. Teakle, L. J. H. Soil erosion and soil conservation. *J. Dept. Agric. W. Aust.* **13.** 273-84. 1936.
14. Union of South Africa. Department of Agriculture and Forestry. Forests in relation to climate, water conservation and erosion. *Bull.* 159. 19-22. 1935.

Fiji

According to Jack (1), " erosion has been taking place for a considerable time in Fiji, as is shown by the general flat topography of the low red hills, the fineness of the soil deposited in valleys and the greater fertility of such soils in comparison with the residual eroded materials." Many profiles examined during soil surveys suggest the complete erosion of the surface horizon and the infertility of several soils can be directly attributed to this cause. Much erosion by water action is masked by the shifting cultivation adopted, which permits of rapid growth of secondary vegetation in eroded areas ; nevertheless, sheet erosion is widespread, particularly in soils overlying soapstone and volcanic tuffs.

Wherever land is cleared of timber and subsequently cleared for cultivation, sheet erosion occurs in the undulating country, gully erosion in the steeper country. Practically all the alluvial flat country of Fiji is under cultivation or pasturage and suffers little damage from erosion, apart from flooding. These soils are generally very fertile and are mostly managed by the Colonial Sugar Refining Company whose methods of liming, green manuring and crop growth give rapid results. Where these soils are left to fallow, they are rapidly covered by a thick mat of sensitive plant and Para and other introduced grasses. Erosion through overstocking is almost absent on the flat pastures, but more noticeable on the hills.

Due to the absence of organic colloids and their peculiar mechanical composition (a high content of fine silt and fine sand), many of the soils of Fiji are very easily eroded. If cultivated, they expand and contract during wetting and drying, forming in some cases a patterned surface, and in others deep and extensive cracks. Where cracks are extensive in soils overlying soapstone, the percolation of water to the slippery soapstone surface has the effect of moving soil en masse on the sloping surfaces. The extent of this movement is controlled by the mechanical composition of the soil, the depth to which cracks extend, the amount of cultivation and the slope of the land.

In the dry zones of the Colony, contour cultivation of the hilly lands is frequently seen, but in the wet zones Indians tend to plough up and down slopes to facilitate drainage, the resulting erosion frequently leading to flooding of roads.

Outside the sugar-cane areas, the Indian peasant tills the soil, plants one crop and continues with that until the soil is exhausted to such an extent that natural regeneration is rather slow. The Fijian shifts his cultivation more frequently ; although this process is also wasteful, the soils are not so exhausted and generally revert rapidly to natural conditions. Also, the Fijian very rarely clean-cultivates his land and some of his

methods definitely tend to counteract erosion, unlike the Chinese market-gardeners, who practice clean-weeding on sloping lands.

The Department of Agriculture is attempting to educate the native in a sounder system of agriculture based on soil management and crop rotation, in the hope that he will limit his work to a definite area on which he will practice contour cultivation, terracing, liming, green manuring and cover cropping.

The principal causes of erosion in Fiji are shifting cultivation, uncontrolled timber cutting, fire and, to a much less extent, grazing. Much accessible land is being rendered infertile and unremunerative. Fiji is still fortunate in that loss of vegetation and erosion have not yet been extensive, thanks to sparse population, but the problem is likely to become steadily more serious and the gradual adoption of a soil conservation and restoration policy is indicated.

Reference (Fiji)

1. Jack, H. W. Soil erosion. *Agric. J. Fiji.* **8.** 4-7. 1937.

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